BUNCHING SYSTEM OF THE KEKB LINAC

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Abstract

At present, the KEK 2.5-GeV Linac is being upgraded as the injector of the KEK B-factory(KEKB). One of the most important changes is to increase the intensities of positron beams injected into a KEKB ring; it is, therefore, required to accelerate high-intensity single-bunch electron beams to high energy, 3.7 GeV, where they are converted to positron beams. For the purpose, the primary electron bunch should have more than 10 nC. Furthermore, the bunch lengths must be limited as short as 10 ps, in order to achieve narrow energy spreads of primary electron beams, and produce positron beams of short bunch lengths, as well. The bunching system has been designed to meet these requirements, introducing subharmonic bunchers(SHB).

This paper describes the upgrade of the bunching system and the results of simulations of bunching using PARMELA. The designs and RF test of SHB cavities are described.

Introduction

The KEK PF 2.5-GeV Linac is now being upgraded for the KEKB project[1]. The pre-injector of the KEKB Linac must provide beams with various charge contents for the KEKB rings and PF ring[1]; single-bunch electron beams of 10 nC for the positron beam production, and 1 nC for direct injection to the KEKB electron ring. The demands to the bunching section lies in the primary electron beams for the positron production; the pre-injector must produce single bunch electron beams of more than 10 nC, furthermore, there exist the optimum bunch lengths according to the charges of the bunches to minimize the energy spreads in subsequent acceleration, determined by the contributions of bunch length and longitudinal wake fields to energy spread. According to calculation results[2], bunch lengths about 10 ps at FWHM are desirable in the case of single bunches of 10 nC.

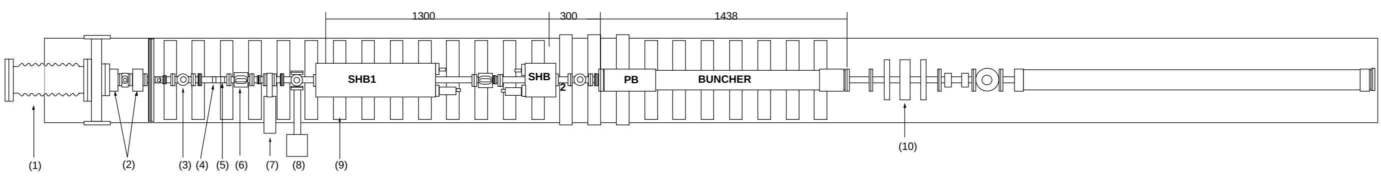
To meet these requirements, the pre-injector system has been designed to introduce two subharmonic bunchers (SHB). The frequencies of the two SHB's was chosen to be 114.24 MHz and 571.2 MHz[3].

We will describe the design of the whole bunching system, and the bunching characteristics, together with the design, fabrication, and RF test results of subharmonic bunchers.

Design of Bunching System

The acceleration studies on high intensity single-bunch electron beams for the KEKB Linac have been carried out at KEK PF 2.5-GeV Linac for a couple of years[3, 4], using one subharmonic buncher(476MHz). And it has been clear from those studies that one more subharmonic bunchers was necessary. to produce single bunches with no satellite bunches if the charge about 10 nC or more[4].

As mentioned above, the electron charges required for the production of positron beams KEKB are 10 nC. We, however, have designed the bunching system with PARMELA so that it could produce single bunches up to15 nC. The layout of the newly designed bunching section is shown in Fig. 1. The bunching system with one subharmonic buncher was described elsewhere[2]. We will briefly describe the new bunching system and bunching behavour below, mainly for the case of 15 nC. To get 15 nC single bunches at the end of the pre-injector, we assumed 20 nC from the electron gun considering charge losses in the bunching processes. In this case, the space charge force is so large that it was necessary to shorten the drift space after the beam was tightly bunched, to minimize debunching. Since the conteracting forces of the space charges make the beam energies convergent with bunching, there exists the minimum possible beam pulse length. In the drift space downstream SHB1, this is about 1000 degrees in S-band or little longer, which corresponds to almost half the wavelength of the rf of SHB2. Furthermore, the SHB1's frequency is so low that the tremendous power is required to provide large modulation. We, therefore, set low the bunching field at SHB, about 50 kV. To compress the above beam pulse length to shorter than one wavelength of the S-band prebuncher, further bunching is required at SHB2 with the peak electric field of 100 kV. In this design, the first prebuncher was removed since debunching occured in drift space between the prebunchers, ans thus the main bunching components of final system include two subharmonic bunchers of standing wave types, and prebuncher(the old PB2) and buncher. The prebuncher and buncher are mechanically joined toghether to minimize drift space, whereas they are separated electromagnetically. One more important change in the pre-injector is to strengthen the electric field of the buncher; the power of the klystron for the pre-injector will be increased twice to provide the electric field



(1)Electron Gun, (2) Magnetic Lens, (3) Profile Monitor, (4) Wall Current Monitor, (5) Core Monitor, (6) Steering Coil, (7) Gate Valve, (8) Ion Pump, (9) Focusing Coil, (10) Q-Magnet

Fig. 1. Pre-injector of the KEKB Linac

*Present address: Atomic Energy Research Institute, Nihon University, Kanda-Surugadai, Chiyoda-ku, Tokyo 101 JAPAN of 20 MV/m for the buncher (present : 15 MV/m). More efficient bunching was confirmed from the results of the simulations in the case of high intensity beams.

Figure 2 shows the parameters of a bunched beam of 15 nC at the exit of the buncher. About 70 % of the initial charges are contained in 15 degrees around the peak. It is shown that single bunches of about 10 ps at FWHM could be obtained. The energy spread is rather broad, but a short bunch length is more important than this energy spread in the bunching section, since the energy dispersion due to the bunch length during subsequent acceleration dominates the total energy spread. In this case, two tiny satellite bunches on each side of the main bunch was formed containing charges of 6 percent of total initial charges. For other charges, shorter bunch lengthes and narrow energy spread was obtained in simulations; 5 degrees and 1.2 MeV for 1 nC bunch, and 10 degrees and 2.0 MeV for 10 nC, all at FWHM.

Simulation on charge 15 nC showed that the optimization of focusing magnetic fields of maximum 1400 G, full capacity of the present focusing coils, could hold the normalized RMS emittance below 150 π.mm.mrad[6].

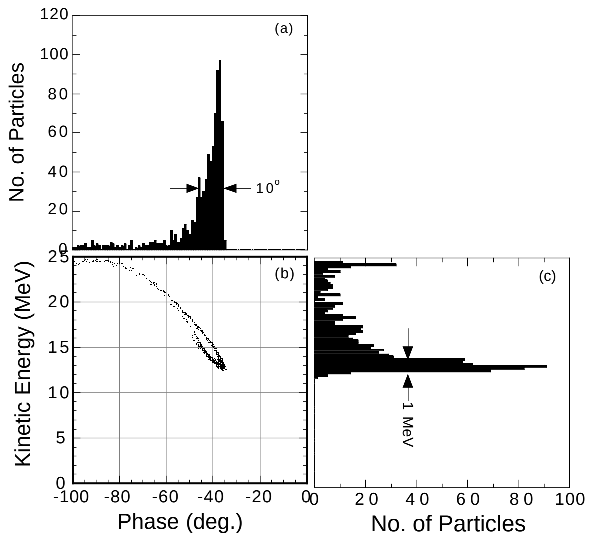


Fig. 2. Characteristics of the bunch of 15 nC at the exit of the buncher. (a)bunch shape; the horizontal axis denotes the phase of a particle with respcet to the fundamental wave in the buncher. (b) the distribution of particles in longitudinal phase space, (c) energy spread

Subharmonic Buncher 1 (SHB1)

The 119 MHz subharmonic buncher cavity [7] is available with the removal of the positron beam line according to the end of the TRISTAN experiments. To examine its usability as the SHB for the KEKB Linac, we measured the main parameters of the cavity and calculated the parameters for the same geometry with SUPERFISH. The results of SUPERFISH showed that minor changes of the acceleration gap structure make the cavity usable as SHB1 of the KEKB Linac as far as the frequency is concerned. But the measured shunt impedance (0.54 MΩ, compared to the calculated value 0.79 MΩ) is so low that it requires a very large peak power for bunching high intensity beams . For example, as mentioned in the previous section, a peak modulation of 50 kV will be necessary for a beam of a pulse width 2 ns and 20 nC in this design. In this case, the peak voltage will be as high as 77 kV. The shunt impedance value shows that the the cavity should be supplied a peak power as high as 11.2 kW to sustain the peak voltage. The shunt impedance of this cavity is made low by large nose tip radii and beam duct diameter near the gap. We designed a new SHB1 cavity and as its shunt impedance is above 1 MΩ, we can fabricate a cavity with the shunt impedance value larger than 0.7 MΩ, and if this is the case, the required peak power become s 8.6 kW.

Subharmonic Buncher 2 (SHB2)

Design and low power RF test. The structure of the SHB2 cavity newly fabricated is shown in Fig. 3. The structure of the cavity is similar to that of 476 MHz SHB cavity[2] . In the case of 476 MHz cavity, a ceramic covering was used over the input coupling loop to isolate vacuum from the atmosphere. By doing so, the coupling of the cavity can be changed keeping vacuum. In this case, we did not use a ceramic covering to prevent electric discharges which may occur in high field operations. The power input connector is joined to the cavity by a rotatable ICF flange, and therefore the coupling can be changed if needed, though it damage cavity vacuum during change.

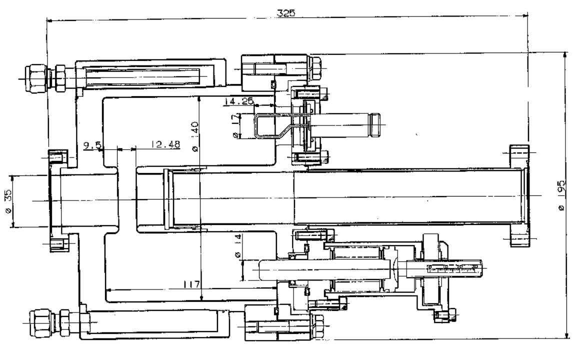


Fig. 3. Structure of SHB2 cavity.

The main parameters of the SHB2 cavity are shown Table 1. The Q value was measured by both the reflection method and the impedance method[8]. The temperature of the cavity was kept constant at 31 ± 0.2 °C by circulating the cooling water used in actual beam line, and vacuum was kept by a turbomolecular pump, lower than 10^{-2} mbar. The cavity has a Q value of 83 % of the calculated one. The shunt impedance of Table 1 was obtained from R/Q values measured by Slater's bead perturbation method[8]. The measurements were done using aluminum spheres of diameter 2,3,4 mm as perturbaters. It is the value obtained when these values are extrapolated to the limit of zero volume. This R/Q value is nearly the same as the one by SUPERFISH. Figure 4 shows the electric field distribution on the beam axis near the acceleration gap. The agreement between measured curve and the calculated one is good. From this shunt impedance value, it can be seen that a peak power 6.7 kW is necessary to get the peak electric field, 100 keV, required to be provided by the SHB2 cavity to bunch 20 nC beams. A SHB2 power source capable of peak power 10 kW is now being fabricated. It will be a sloid state amplifier and completed in this fiscal year.

Table 1.
Main parameters of the SHB2 cavity

	Calculated	Measured
Cavity Length	117 mm	
Gap Length	12.2 mm	12.48 mm
Resonant Frequency	571.2 MHz	
Tuning Range	570.44 - 572.32 MHz (total stroke of tuner : 30mm)	
Q_o value	10,870	9010
Coupling Parameter	1.4	
Shunt Impedance	1.83 MΩ	1.50 MΩ

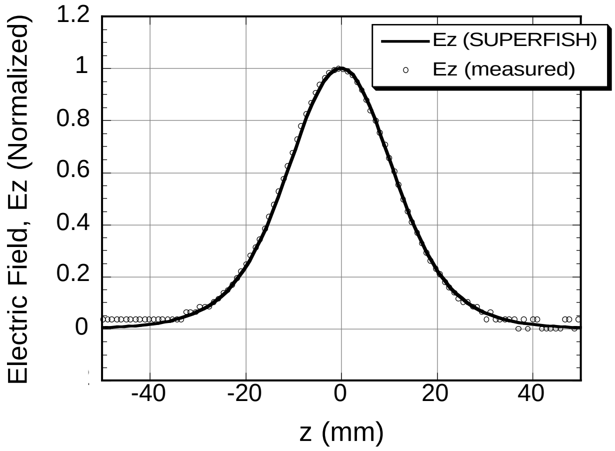


Fig. 4 Electric field distribution on axis near the acceleration gap of SHB2.

High Power Test. Since a high power source of 571.2 MHz is not available to us at present, as a preliminary test, we performed a high power test of the newly fabricated cavity using the 476 MHz power source which is installed in the present beam line. To adjust the resonant frequency of the cavity to 476 MHz, we inserted a copper spacer of thickness 26.7 mm in the cavity and lengthened the cavity.

The test was done at 31± 0.2°C, and 3×10^{-7} mbar. The electric discharges by multipactoring has been observed during initial rf aging, and we perfomed the high power tests at various levels through two days. We finally put peak power 4.2 kW into the cavity , though this is not a sufficient level. We confirmed a stable operation with no continuous electrical discharge up to this level except for initial stage discharges. Figure 3 shows the power pulses observed by an oscilloscope.

When a 571.2 MHz power source becomes available, we will perform again high power test through the full range at the resonant frequency.

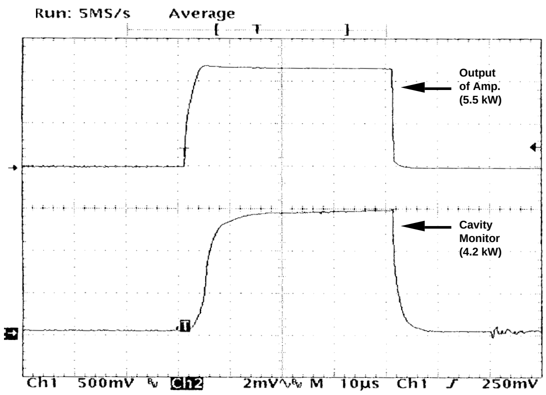


Fig. 3. Power pulse forms in high power test observed at power source (above) and cavity monitor(below)

Conclusion

We designed the bunching system for the KEKB Linac by simulation code PARMELA. The result showed that the newly designed bunching system can produce bunched beams required for the KEKB pre-injector. We fabricated a new SHB cavity and confirmed that it has required properties. Another SHB cavity will be fabricated in the near future.

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