OPTIMIZATION STUDIES ON BEPCII FUTURE PRE-INJECTOR WITH TWO SUBHARMONIC BUNCHERS

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Abstract

The BEPCII future pre-injector consists of a thermionic gun followed by two subharmonic bunchers (SHB), a travelling wave prebuncher and a travelling wave buncher. All components downstream of the gun are immersed in a solenoid field. Beam dynamics simulation and optimization have been carried out with programs PARMELA and EGUN. SHBs' bunching voltage and bunching drift distance, prebuncher's and buncher's phases and acceleration gradients, and solenoid field profile have been studied.

INTRODUCTION

In order to further increase the injection rate of positron beam, the pre-injector is planned to have the capability of providing a low emittance and high intensity single bunch electron beam for the positron beam production. For this purpose, the primary electron bunch needs to have more than 9 nC charge, and the bunch length at the buncher exit needs to be limited as short as 10 ps to meet the longitudinal acceptance of downstream RF accelerating structures. Furthermore, BEPCII will adopt two-bunch generation and acceleration scheme to double the positron injection rate into the storage ring in the future, so it is very important to have a new pre-injector with good bunching characteristics. To meet these requirements, a new pre-injector has been designed and optimized by introducing two subharmonic bunchers. With this new pre-injector, an initial 1.5 ns electron bunch at the gun exit can be bunched to 10 ps at the buncher exit, with bunch charge of more than 9 nC.

FREQUENCY SELECTION

Table 1: Various frequency relations

	Multiple	Frequency [MHz]	Period [ns]
Common Frequency	1	17.85	56.02
SHB1	8	142.80	7.000
SHB2	4×8	571.20	1.751
Linac	5×4×8	2856.00	0.350
Ring	4×7	499.80	2.001

To ensure a precise injection timing and make the injection flexible, the subharmonic buncher (SHB) frequencies as well as the linac frequency (2856MHz) must be phase-locked to the ring frequency. In the BEPCII design the ring frequency of 499.8 MHz and the linac frequency of 2856 MHz have been decided, so the common frequency of 17.85 MHz can be selected. As a consequence, the two SHB1s' frequencies can be chosen to be 142.8 MHz and 571.2 MHz. The frequency relations between the linac and the ring are listed in Table 1.

SIMULATION AND OPTIMIZATION

Optimized layout of the pre-injector

By a great deal of beam dynamics calculations with the program PARMELA, we have proposed the optimized layout of the BEPCII future pre-injector, as shown in Figure 1.

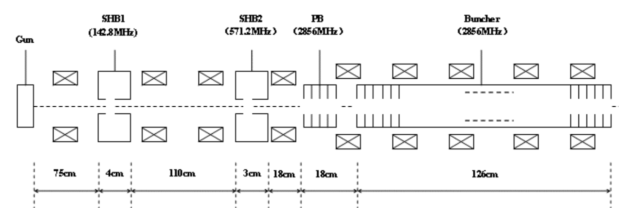

Figure1: Schematic layout of the components for the BEPCII pre-injector with 2 SHBs.

Electron gun

The electron gun is a conventional thermionic triode gun with EIMAC Y796. The gun voltage of 150 kV has been chosen. When the gun works with narrow pulses, the emission current can be 12 A or more. The normalized emittances at the gun exit are 20-25πmm.mrad for emission currents from 6 A to 12 A. The gun's geometry has been simulated and optimized by code EGUN to minimize the emittance for a 10 A bunch current. Figure 2 shows the beam optics of the electron gun with a bunch current of 10A and a normalized emittance of 20.34πmm.mrad at the gun exit.

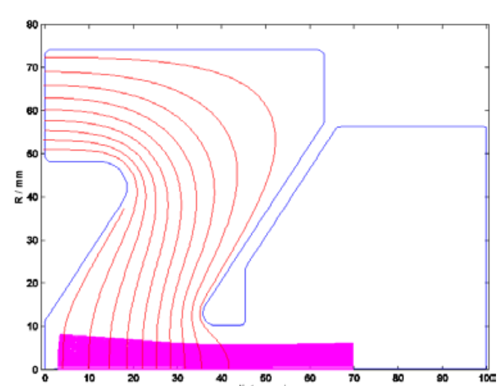

Figure 2: Beam optics of the electron gun.

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Guidelines on simulation and optimization

Starting with the transverse beam parameters at the gun exit calculated with EGUN, a 10 nC/150 kV and 1.5 ns electron bunch is used as an input of PARMELA simulations. At the buncher exit the energy of the particles is about 16~20 MeV, the normalized rms bunch emittance is expected to be less than 20 πmm.mrad, with more than 90% of the initial particles in the phase spread of 10^o at 2856 MHz.

The first SHB is located at a distance of 75 cm downstream from the gun. This distance is needed to install some equipment, such as the beam monitors to check the beam current, size, emittance and the beam position at the gun exit, the solenoid lens and other focusing lens to focus and match the beam into SHB1, and a vacuum valve and vacuum pumps.

To have the best bunching results, the following guidelines have been applied:

- At the entrance of SHB2, more than 95% of the initial particles need to be found in 120^o of 571.2MHz;
- At the entrance of the prebuncher, the bunch length is expected to be about 0.18 ns;
- In order to suppress the emittance growth caused by energy spread, SHBs' voltages need to be as low as possible, but the voltages must be not too low due to the space charge effect;
- The distance between prebuncher (PB) and buncher (B) is preferred as short as possible for evading any de-bunching effects;
- In order to control the beam size and minimize the emittance growth due to space charge effects, all components of the pre-injector need to be immersed in a solenoid-focusing field;
- High PB acceleration gradient is bad for bunching, but low PB acceleration gradient is bad for suppressing the space charge effect, so the PB acceleration gradient needs to be optimized carefully;
- The Buncher acceleration gradient is expected as high as possible for suppressing the space charge effect and completing the bunching process rapidly.

Followed the above criteria the optimized bunching system shown in Figure 1 has been found.

Selection of the principle components' phase

If the reference particle in the middle of the electron bunch reaches the SHBs at the zero phases of SHBs, then the velocity differences between the head particles and the reference particle will be smaller than the velocity differences between the tail particles and the reference particle. This effect will cause the beam emittance growth due to the longitudinal asymmetry of the particle distribution. Therefore, the reference particle must be not on the zero phases of SHBs when the bunch is modulated by SHBs. For the optimization of the BEPCII future pre-injector, the reference particle is put on the decelerating phase of SHB1 and on the accelerating phase of SHB2. It was found that if the reference particle's energy decreases 20 keV to 130 keV in SHB1 and then increases 20 keV to 150 keV in SHB2, the best bunching result can be obtained.

The prebuncher of the pre-injector is a 4-cell, β=0.75, 2π/3-mode S-band traveling wave structure. In this kind of structure, there must be a relation between the input phase and the output phase of the particle. Figure 3 shows the relation between the input and output phases of a single particle motion at an acceleration gradient of around 6.32 MV/m. The shape of the curve may vary a little when the acceleration gradient is different from 6.32 MV/m, but they are alike. By this figure, the injection phase of the reference particle at the prebuncher can be chosen at the bending point of the curve if the reference particle is at the mid-bunch. Otherwise, the phase needs to be adjusted according to the differences between the reference particle and the particles at the mid-bunch.

The injection phase of the reference particle at the buncher can also be chosen in the same way as that at the prebuncher.

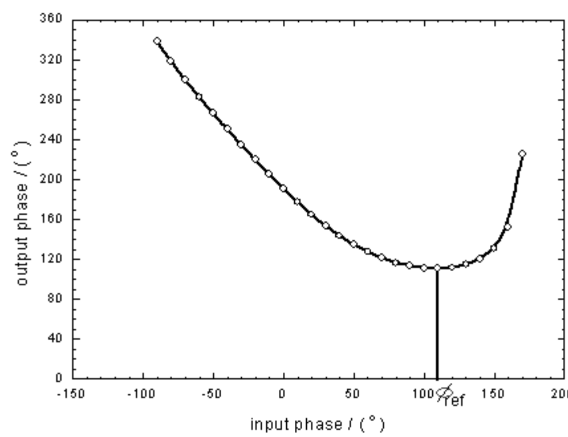

Figure 3: Relation between the input phase and the output phase of the prebuncher.

Transverse beam dynamics

In dealing with the optimization of transverse beam dynamics, two key points need to be considered. One is the capture efficiency at the buncher exit, another is the emittance variation along the whole pre-injector. If the strength of the solenoid field is higher than 1380 Gauss, the capture efficiency at the buncher exit will be lower than 90%. On the other hand, if this strength is smaller than 1050 Gauss, the emittance at the buncher exit will exceed 20 πmm.mrad. So the strength of the solenoid field is usually larger than 1050 Gauss and smaller than 1380 Gauss, and the optimal value is 1300 Gauss, as shown in Figure 4. The profile of the solenoid field can affect the emittance variation along the whole pre-injector, so this also needs to be optimized to minimize the variation. Figure 4 shows the solenoid field and emittance variation along the whole pre-injector, in which all the parameters of the principle components are optimized.

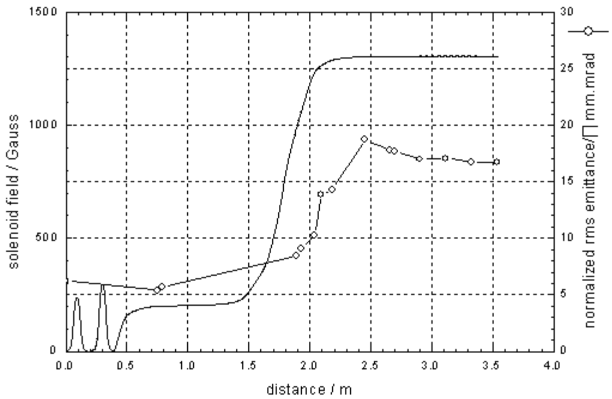

Figure 4: Solenoid field and emittance variation along the whole pre-injector.

Results of simulation and optimization

Table 2: Parameters of the principle components

Parameters	SHB1	SHB2	PB	Buncher
Frequency [MHz]	142.8	571.2	2856	2856
Bunching voltage [kV]	60.84	89.96		
E_0T [MV/m]			6.32	21.0

Through many simulations and optimizations on the pre-injector, if the 150 kV/10 nC electrons within a pulse length of 1.5 ns are emitted from the gun and come into the bunching system with the parameters listed in Table 2, then at the buncher exit: a) more than 90% of the initial particles can be found in 10^{o} of 2856 MHz; b) the normalized rms emittance is 15.64 πmm.mrad; c) the beam energy is 18.41±1.99 MeV with its rms energy spread of 4%. All of these parameters can satisfy the requirements. Figure 5 and Figure 6 shows the simulation results with program PARMELA, indicating that the designed beam characteristics of a high intensity, single-bunched beam can be obtained using the optimized pre-injector with the parameters listed in Table 2.

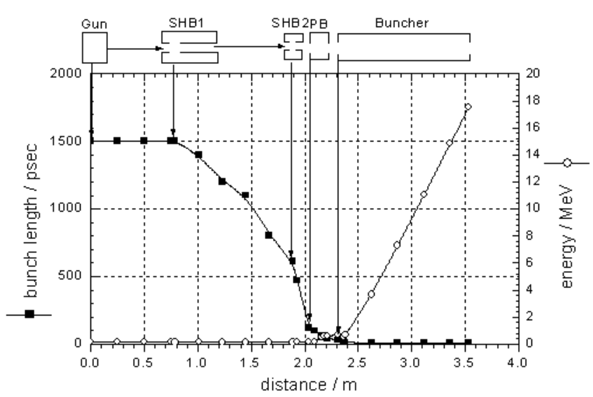

Figure 5: Simulation of the beam dynamics from the gun to the buncher exit.

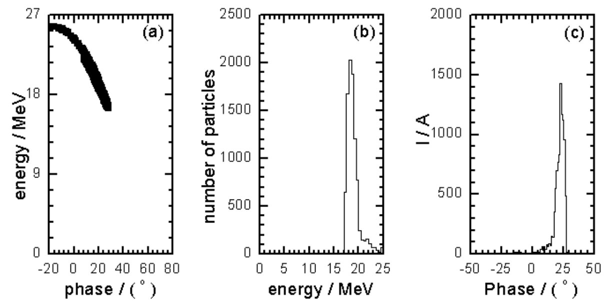

Figure 6: The beam phase space at the buncher exit.

CONCLUSION

Using the optimized pre-injector, more than 9 nC charge can be bunched into 10 ps of S-band, with normalized rms emittance of smaller than 20 πmm.mrad.

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REFERENCES

[1] PEI Guo-Xi et al. Preliminary Design Report of BEPCII-Linac, IHEP-BEPCII-SB-03, 2002.6

[2] WANG Shu-Hong, WANG Jiu-Qing, YE Qiang et al. High Energy Phys. and Nucl. Phys., 2002, 26 (12): 1302 (in Chinese).

[3] WANG Shu-Hong, GU Peng-Da, WANG Jiu-Qing et al. High Energy Phys. and Nucl. Phys., 2003, 27(2): 173

[4] GOU Wei-Ping. Physical Design of BEPCII Positron Source. Master Thesis, IHEP, 2001 (in Chinese)

[5] Yeremian A D et al. SLAC. Handbook of Accelerator Physics and Engineering. Ed. Chao A W, Tigner M. World Scientific, 1999. 419

[6] Young L M et al. Parmela. LA-UR-96-1835, Los Alamos National Laboratory, Recisied July 30, 2002

[7] Herrmannsfeldt W B. Egun-An electron optics and gun design program. SLAC-331, UC-28, (A), 1998.10

[8] Abe I, Akasaka N, Akemoto M et al. Nuclear Instruments and Methods in Physics Research, 2003, A 499: 167-190

[9] Pisent A, Rinolfi L. Proceedings of the bunching workshop. Ed. Rinolfi L. CERN/PS 92-07 (LP), 1990. 99

[10] ZHOU Feng, Braun H. Updated Beam Dynamics for a CTF3 Injector. CTF3 Tech.-Note 2000-015/Injector, 2000.9

[11] Yeremian A D, Miller R H. Micro Bunches Workshop. Ed. Blum E B, Dienes M, Murphy J B. AIP Press, 1995.