OVERVIEW OF BEPCII LINAC DESIGN

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Abstract

The BEPCII fundamental requirement to its injector linac is a very stable positron beam of 1.89GeV and 40mA with the energy spread less than ±0.5% to reach a 50mA/min injection rate. For the energy issue, the 45MW TH2128C will be utilized to replace the 30MW HK-1klystrons. For the beam current issue, we're going to use a new high current electron gun to increase bombarding beam current, and use a new positron source to improve positron capture efficiency. At the same time, a SLAC 5045 klystron will be used at the second RF power station (K_2) and the correlated RF structures will be also replaced so as to increase the bombarding beam energy from 140MeV to 240MeV.

1 INTRODUCTION[1,2]

The BEPC injector is a 1.3 GeV electron linac, which was built in 1986 and has been in service for almost 15 years. The main parameters at linac end are energy of 1.3GeV, positron beam current of 4~5mA, bunch width 2.5nS and repetition rate 12.5Hz. The electron beam energy for positron production is 140MeV and routine positron injection rate into the ring now is about 3mA/min. BEPCII, to be upgraded with a luminosity of $1\times10^{33}cm^{-2}s^{-1}$@1.89GeV, has been approved recently. The luminosity is almost two orders of magnitude higher than that of existing machine BEPC. It needs full energy injection at 1.89GeV, and a positron injection rate of 50mA/min. Table one shows the main parameters of BEPCII injector. Among these parameters, the positron injection rate is very demanding. It is almost one order of magnitude higher than that of BEPC routine operation. We're going to take the following measures to get the needed filling rate:

- Increasing repetition rate from 12.5Hz to 50Hz ×4
- Increasing bombarding electron energy from 140MeV to 240MeV ×1.7
- Increasing primary e^- beam current on target from 2.5A to 6A ×2.4
- Improving positron yield at the linac end from 1.4 to 2.6% $e^+/(e^-\times GeV)$ ×1.9

But considering the storage ring frequency is changed from 200MHz to 500MHz, we will use 1 ns electron pulse, and the charge per pulse will be decreased 2.5 times. So the total charge gain per pulse is about 12.4 times. During the BEPC linac upgrades, the transport line's transmission and the injection efficiency into the ring will be also greatly improved. A 50mA/min. injection rate is possible.

- New electron gun: 10A, 1ns, 10nC
- Electron charge at target: 6A, 6nC
- UF solenoid exit: 62mA, 62pC (4.3% $e^+/(e^-\times GeV)$)
- Linac end: 37mA, 37pC (60% transmission)

Suppose the transmission rate of transport line (BT) is 60%, and filling efficiency into the ring 80%, then the injection rate will be

$$37\,pC/pulse \times 50\,pulse/s \times 0.6 \times 0.8 \div 802ns = 1.1mA/s$$

Additionally, the two-bunch acceleration technique has been studied at KEK and got some satisfied results. We're going to adopt this technique later and hope to get 60% more injection rate.

Table 1 Parameters of the BEPCII injector linac

Energy	1.89	GeV
Energy spread （e+）	≤±0.5	%
Emittance （e+）	1.6	mm.mrad
Positron current at linac end	37mA	2.3×10^{8}
Gun (EIMAC Y796) DC high voltage Bunch current Macro bunch width Repetition rate Macro bunch separation	 120~200 10A 1.0 50 56.02	 kV 6.25×10^{10} ns Hz ns
Positron system Target (W) Primary e^- energy Primary e^- current Peak field of FLUX UF field of solenoid e^+ yield at solenoid end e^+ yield at the linac end	 8 240 6A 4.5 0.5 0.043 0.026	 mm MeV 3.7×10^{10} T T $e^+/e^-\cdot GeV$ $e^+/e^-\cdot GeV$

2 BEAM CURRENT ISSUE

2.1 *Electron gun*[2,3]

The BEPC cathode is EIMAC Y824. For 2.5ns pulse at 80kV anode voltage, the limited emission current is 5A. Like other high luminosity colliders, BEPCII needs much higher intensity and better quality electron gun system. Y796 has been proved to be a good candidate for higher emission cathode. In the space charge limit region, the maximum anode current is predicted to be 12A at an injection voltage of 160kV. Figure 1 shows the gun optics calculated by the electro-trajectory program of W.B.Hermannsfeld. In the calculation the current was assumed to be 12A, which is the actual value of a short-pulsed beam (2ns). The calculation predicts a perviance of $0.19\mu A/V^{3/2}$ and an emittance of $1.4\times10^{-2}\pi(m_0c\cdot cm)$.

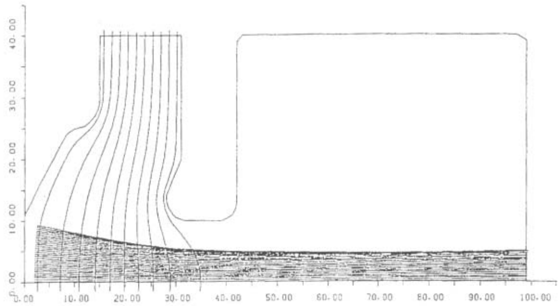

Figure 1 Computer plot of the gun optics at 160 kV showing equal-potential surfaces and the beam-focusing pattern. Shaded area denotes the electron beam. The emission current is assumed to be 12A.

2.2 Electron energy for positron production

Figure 3 shows the layout of the BEPC linac. It's a 202meter electron linac with 16 RF power sources and 56 SLAC-type RF structures. The RF driving system consists of a 2856MHz master oscillator, a PSK and a 1kW solid-state amplifier, which will be used to drive the first RF power source K_1 (subscript stand for location). K_1 is mainly used for driving pre-injector, including an electron gun, a pre-buncher, a buncher and an electron booster A_0. Part of K_1 output power will be used to drive the other 15 klystrons through a 20dB directional coupler and the 1 5/8″ rigid coaxial line. Positron production system is located at down stream of second RF power source. K_3 drives positron capture section SC (the first RF structure following positron convert target), and K_4 drives another two RF structures to boost positron beam energy to more than 100MeV. Except for K_1, K_3 and K_4, the other RF power sources are working with SLED to drive the regular acceleration sections, which consists of four SLAC 3m constant gradient accelerator tubes. The design electron energy for positron production at the BEPC was 150MeV, while that at the BEPCII is 240MeV. For the RF power source, we can use SLAC 5045 to replace the HK1 klystron.

When we installed BEPC 250MeV section (positron production system) in 1986, the high power dummy loads were not properly baked and the degassing contaminated the whole RF structures. Since the new accelerating gradient will be about 20MeV/m, we will have to replace the eight existing tubes with new ones.

2.3 New positron production system[2,4]

The BEPC positron source is also shown in Figure 3. It consists of a ϕ10×6 mm tungsten target, a two-coil pulsed solenoid used as flux concentrator with peak field of 2.6T, a 9m long UF solenoid with the field of 0.35T, three SLAC type RF structures, and power supplies, etc. Built in 1986, the maximum positron beam was about 9mA at linac end with electron beam power of 150MeV and 2.5A. The positron yield was 2.4%. But the routine positron beam is only 4~5mA now, presumably because the system or some components were suffering from aging problems and couldn't work at their design values. Some of the early designs were also dissatisfactory. For example, steering coils couldn't efficiently compensate the 0.5Gs dipole field of the UF solenoid, pulsed solenoid had the potential problem of break, the system was uneasy for maintenance, etc. All these problems are now becoming the bottleneck for the BEPC operation and the further development. The BEPCII will use a new system.

The BEPCII linac is very similar to the DAϕNE linac. Both are inline machines with almost the same primary electron beam power of 250MeV and 4A for positron production. We're going to refer to the DAϕNE positron converter as well as UF focusing system, but engineering design will be a little different, which depends on the state of art for manufacture. The capture system is essentially composed by a tapered field UF solenoid, with a peak of 1.2T, and by a pulsed coil, the SLAC design flux concentrator, which generates a solenoid field that drops adiabatically from the peak of 3.7T to zero in about 12cm. Figure 2 shows the EGS4 and PARMELA simulation results for both BEPC and BEPCII positron sources. Square curve is the BEPCII positron yield as a function of electron beam size on target, while diamond curve and triangle △ of 1.6%$e^+/(e^-\cdot GeV)$ are for the BEPC design and present value separately. So if we increase UF field from 0.35T to 0.5T, the positron yield can be increased about 70% from 3.2% to 5.5% $e^+/(e^-\cdot GeV)$ at the end of solenoid with electron beam radius of 2.5mm. The figure also shows the electron beam size makes great contribution to positron yield. Simulation shows a primary electron beam radius of about 1~1.5mm is possible.

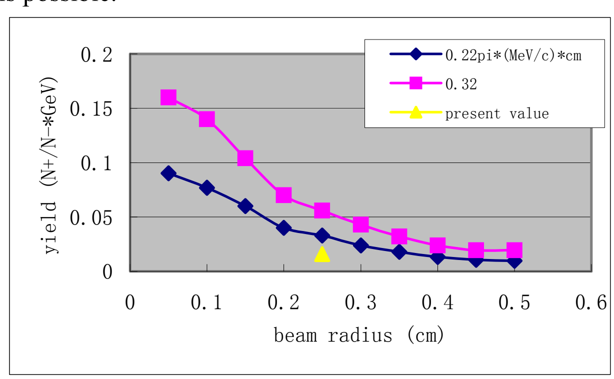

Figure 2 Positron yields vs electron beam radius

3 TWO-BUNCH INJECTION[5]

The BEPCII ring RF frequency has been chosen as 499.8MHz, and the linac frequency is 2856MHz. So the common frequency is 17.85MHZ(2856/160, 499.8/28). The minimum bunch space is 56.02ns for synchronous acceleration. According to the KEKB linac experience, the two-bunch injection is possible, but not an easy job. The main issues are under investigation, such as two-bunch generation, acceleration and bunch selection for injection etc.

Another multi-bunch injection schemes are also possible since the BEPC II longitudinal acceptance is about 1ns. Minimum bunch gap of 8.05ns is exactly synchronized for linac, and not too bad for the ring. In this case, the two-bunch mode is much easier, and a three-bunch mode is possible. The big issue is how to make them equally accelerated.

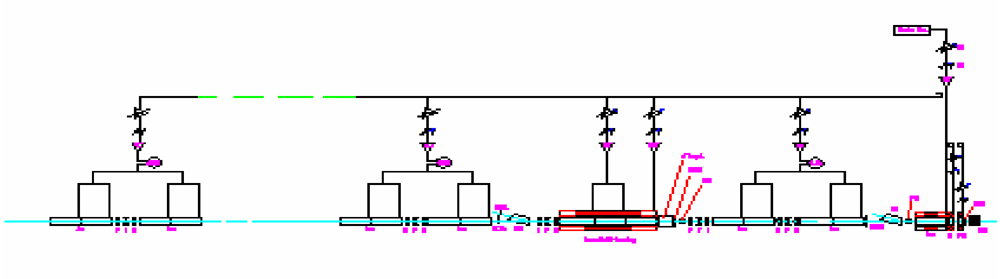

Figure 3 Layout of the BEPC linac

4 RF POWER SOURCE[6]

For the SLAC type RF structure, the energy gain for each regular section of 4 accelerator tubes driven by one klystron can be expressed as

$$\Delta E = 20M[P]^{1/2}$$

Where M is the multiplication factor of SLED, P the output power of the klystron. K_2 will use a 65MW SLAC 5045(working at 50MW) to increase the primary electron beam energy to 240MeV. K_{12} has already used a SLAC 5045 and will keep working at 45MW. The other 14 klystrons will be Thomson TH2128C. Down stream of positron production system, there are 12 such regular acceleration sections. If TH2128C works at 35~40MW, the total energy gain is

$$\Delta E = 20\times 1.5\times\sqrt{45} + 11\times 20\times 1.5\times\sqrt{35} = 2.15GeV\ .$$

Considering the initial energy of 80MeV at UF solenoid exit, the positron beam energy at linac end will be about 2.2GeV, 16% higher than the design specification. The extra gain will be used for one klystron standby in case of failure, and energy tuning.

The BEPC 80MW modulators were designed for 30MW HK1 klystrons. The peak beam voltage and peak beam current are 265kV and 290A, respectively. Since new RF power source will use TH2128C, especially working at 50pps, we need make big improvements to the existing modulators. Beam transformer of ratio 1:15 will be used to get the required peak beam voltage and current. DC power sources for modulators also need to be improved. Another important issue for modulator development is the stability. ±0.5% energy spread requires that modulator beam voltage stability, including pulse-to-pulse jitter and long-term shift, be less than ±0.1%. Recent experiments showed the beam voltage stability even with DeQing was about ±0.5%, not the design value of ±0.1%. The measures for solving this problem are, improving DeQing circuit, stabilizing AC power within ±2% and thyratron and bias power supply for beam transformer working properly, etc.

5 BEAM QUALITY AND STABILITY[2,7]

In previous chapters, we emphasized on positron beam energy and beam current issues. To any high luminosity collider injector, the beam quality, for instance beam energy spread, beam emittance etc, and machine stability are extremely important. Otherwise, the injection rate cannot be high even the beam intensity is strong enough. In order to quarantee the beam quality and stability, except for making the modulator much more stable, we will adopt beam optics and orbit correct system and phasing system, rebuild linac control and beam instrumentation. Especially we will put 16 BPMs and two emittance measurement devices in the linac. The system tolerances are much tighter.

6 REFERENCE

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