PROGRESS OF THE BEPCII LINAC UPGRADE

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Abstract

BEPCII is the second phase construction of the Beijing Electron Positron Collider (BEPC). It requires its injector linac to have higher beam energy (1.89GeV) for on-energy injection and a higher beam current (40mA e+ beam) for a higher injection rate (≥50mA/min.). The low beam emittance (1.6πmm-mrad for e+ beam, and 0.2πmm-mrad for 300mA e- beam) and low beam energy spread (±0.5%) are also required to meet the storage ring acceptance. Hence we need a new electron gun system, a new positron source, a much higher power and more stable RF system with its phasing loops, and a new beam tuning system with orbit correction. Up to date, all system design and fabrication work have been completed. And in five months from May 1st of 2004, the positron production system—from the electron gun to the positron source, has been installed into the tunnel. In this paper, we will introduce major upgrades of each system, and present the recent beam commissioning.

INTRODUCTION

BEPCII[1] is a factory type e^-e^+ collider with a luminosity of $1\times10^{33}\,cm^{-2}s^{-1}$ in the Tau-Charm energy region (2-5 GeV). On-energy injection scheme with an injection rate of > 50mA/min (ten times of present value) for e^+ beam requires the existing BEPC injector linac to be upgraded with higher performance[2]. The main parameters are listed in table 1. From the table we can see, the challenging work is to produce more positrons with higher energy and good beam quality.

Table 1: Main Parameters of the BEPCII-Linac

	Unit	e^+ beam	e^- beam
Energy	GeV	1.89	1.89
Current	mA	~ 40	~ 300
Emittance	πmm-mrad	1.60	0.20
Energy spread	%	0.50	0.50
Injection rate	mA / min	> 50	> 300
Pulse repet. rate	Hz	50	50
Beam pulse length	ns	1.0	1.0

To accomplish the task, we need a new electron gun, a new positron source with a flux concentrator, a new RF power system with its phasing loop and a beam tuning system with the orbit correction and optics tuning. Up to now, all system upgrades are going smoothly. We have the first positron beam of ~50mA at the linac end on March 19th, 2005. The electron beam out of gun is ~10A, and ~ 6A at the positron converter target as simulation predicted. Almost all 16 RF power sources have been rebuilt, and stably work at 50pps. New control and beam instrumentation makes the machine commissioning and operation much easier.

ELECTRON GUN

In order to increase the positron current as well as the injection rate, a new electron gun that can emit higher current is needed. A thermionic triode gun with a cathode-grid assembly of EIMAC Y796 is employed. A Kentech pulser is used to produce 1ns pulse. By proper delay and combination, we can also produce two pulses separated by about 56ns for the two-bunch operation. The 150-200keV high voltage is provided by a pulsed power supply. EGUN simulation shows a 12A electron emission at 150keV. The micro-perveance is 0.22μP, and the emittance 17.6μm. During tests at gun test stand with a Faraday cup and linac operation with a beam current monitor (BCT), we'v got ~12A electron beam at the gun exit, which agrees very well with simulation result. Figure 1 is the picture of the gun test stand (left) and the produced two pulses (right). Figure2 shows the emitted current's dependence on the gun high voltage. On a limited space downstream the gun to pre-buncher, we put two focusing lens, two steering coils, two BPMs, and a profile monitor for having a well beam alignment and tuning.

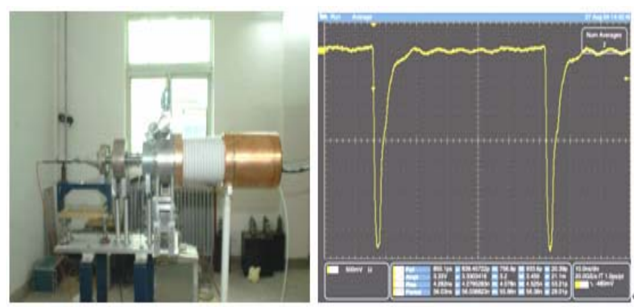

Figure 1: Picture of gun test stand (left) and its produced two pulses(right)

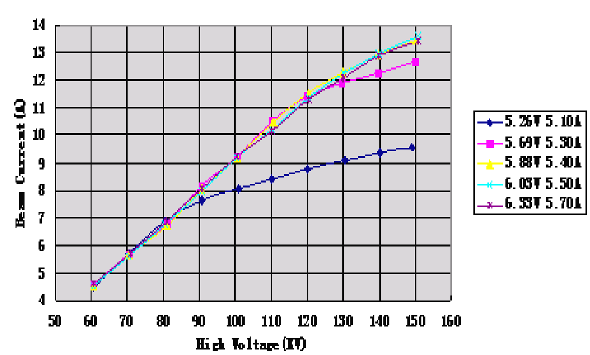

Figure 2: Emitted current vs the gun high voltage

POSITRON SOURCE

The BEPCII positron source[3] is a conventional source. Electrons are accelerated to 240MeV in the linac, and focused to about a 3-5mm diameter spot on a tungsten target. The target itself is a 10-mm diameter, 8-mm thick disk. The disk is copper plated, soldered with its cooling tubes, and post-machined to size. The target arm assembly is suspended and supported in the vacuum chamber by the target housing mounted outside the chamber. A bellows is used to feed the target into the vacuum chamber and provide a flexible pivot. The actuation system is an eccentric axletree. With a stepping motor, it can easily move the target in and off the beam line.

SLAC type flux concentrator[4](FLUX) is used as the matching device. It is a 12 turns, 10cm long copper coil with a cylindrical outside radius of 53mm and a conical inside radius growing from 3.5mm to 26mm. The 0.2mm gaps between the individual windings are manufactured by electric discharge machining out of one copper block. Excitation current and water-cooling is provided by a hollow rectangular copper conductor brazed to the outside of the coil (also 12 turns).

The flux modulator provides 12kA in a 5μs sinusoidal half wave current at 50pps to produce an adiabatic magnetic field profile with the peak of 4.5T at the flux entrance face. The modulator design only uses 2 CX1536 thyratrons to generate pulse current and uses RC auxiliary circuit and energy dump circuit to minimize inverse voltage. Downstream the FLUX, there are seven DC focusing modules wrapped on the RF structures, each 1-meter long with a field of 0.5T, to further focus and matches the positron beam into the downstream quadrupole focusing system. The capture section and booster section are the common SLAC type RF structures, but 20MV/m accelerating gradient is required. EGS4 and PARMELA simulation shows a positron yield of 4.3% (e^+/e^-.GeV)[2][5] is possible with a primary electron beam size of 5-mm in diameter. Figure 3 is the picture of the BEPCII positron source.

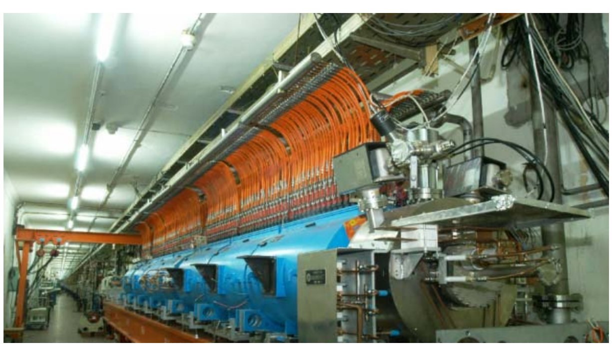

Figure 3: Positron focusing and accelerating system

HIGH POWER AND LOW LEVEL RF SYSTEM

The linac is 200 meter-long, and there are 16 RF power sources in the klystron gallery. Downstream the positron source, 12 regular acceleration sections (one klystron with a SLED drives 4 SLAC-type RF structures) boost the positron beam to 1.89GeV. So the 50MW klystrons (some TH-2128C of 45 MW, others E-3730A of 50MW) are needed to replace the original 30MW tubes. The second RF power station is special for boosting the electron beam to bombard the positron converter target, and the 65MW SLAC 5045 is required. All the 16 modulators are rebuilt for 50pps, 360A beam current and 320kV beam voltage operation. The De-Qing circuit is adopted to keep the beam voltage stability within ±0.1%. Figure 4 is the main BEPCII modulator parameters (left) and the circuit diagram (right).

Parameters	unit	
PFN pulse width (50%)	μs	6.5
PFN unit capacitance	nF	32
PFN unit inductance	μH	3.0 (max)
PFN resistance	Ω	4.2
Pulse transformer ratio		1:15
thyratron peak current	A	5250A
thyratron peak voltage	KV	42
peak power	MW	110
average power	KW	130
repetition rate	Hz	50 (max 100)
rising time (10%-90%)	μs	0.8
fall time (10%-90%)	μs	1.8
pulse stability	%	±0.15
input voltage	V	380 (3φ, 50Hz)

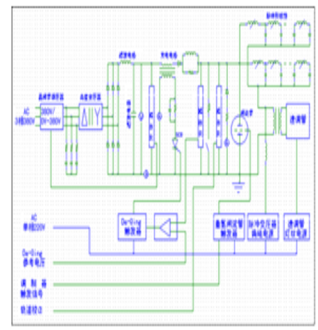

Figure 4: Modulator parameter and the circuit diagram

A new low level RF system is being developed. The maximum energy method is adopt to define the optimum phase, which appears preferable to the beam loading and beam induced methods. To guarantee the phase stability, the frequencies of the ring and the injector linac must be phase locked. Figure 5 is the schematic diagram of the phasing system.

The PAD design is based on I/Q demodulator technique, which can detect the RF phase with an accuracy of 0.2° and the amplitude of 0.1%. The new IϕA unit has an insertion loss of 2 dB, maximum attenuation of 20dB and phasing range of > 360°. The reference line is 7/8in Andrew Heliax phase stabilized co-axial cable, the temperature coefficient is 4ppm/°C. A master oscillator with high phase and amplitude stability is demanded. The tough issue for the low level RF development is the E.M. noise. After many trials in the klystron gallery, we finally got satisfied results with the minimum RF phasing system experiment at the 1st RF unit, and the phase error was well controlled within ±2°.

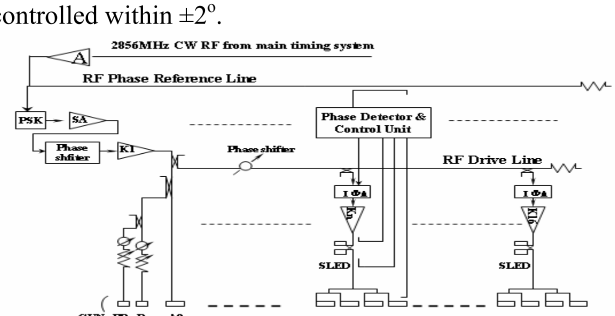

Figure 5: Schematic diagram of the phasing system

ELECTRON AND POSITRON BEAM COMMISSIONING

The positron production system, including the electron gun, 40MeV pre-injector, 200MeV booster section and the positron source, has been installed into the linac tunnel in five months from May 1st to the end of Oct., 2004. After the installation, we took less than one month to start up the machine and process the new systems, because the coming run machine operation for BSRF was assigned to start from the December. We got the first new electron beam at the linac end on schedule on Nov. 19, 2004. Except for BSRF operation, a lot of machine time is required for the fixed target beam test and the intensive low energy positron beam. Thus, we can only have very limited time for linac itself machine study or beam test. But with the limited time we really have done many tests for measuring the electron bunch emittance and commissioning the positron system. In what follows, we will summary these experiments.

The first electron beam test was done on Dec. 2, 2004. A fluorescence screen profile monitor and a quadrupole downstream the pre-injector were used to measure the beam emittance. The experiments were conducted at different beam currents of 1.8A, 4.6A, 7A and Q-scanning method gave an increasing normalized emittance from 1 to 5μm which seems can be explained by the space charge effect and wake field. To a medium current of 4A, the result of 3μm was compatible with the result measured a year ago for BEPC linac, but much worse than the simulation prediction. We suspected the emittance growth was caused by misalignment, and a supporting evidence was x and y emittance were quite different. Since almost all components were well aligned during installation, the attention was paid to the two lenses right downstream the gun. We made special supports for the thin lenses and realigned them again. But the measured results were not much improved.

We observed the beam spots on the screen were not stable, caused by the low energy beam dissipation and discharge. So we used the quadrupole right upstream the positron converter target instead to do the experiment, where the beam energy is much higher. Still, the experiment results were not satisfied. During checking all the experiment process, we found the beam spot size measured by data acquisition and processing was almost twice as much as that with eye investigation. This should be the problem caused by the light saturation of camera, and we took many measures to fix the bug, for example, reduce the camera aperture and add some filter.

On April 7, 2005, we made the final experiment for the electron beam, and got a 5.5A, 180MeV, 0.74μm electron beam at positron converter target, a 0.5A, 1.3GeV, 0.14μm beam at the linac end. The electron beam currents are not our concern, and the experiment results are in reasonable agreement with simulation results.

As to the positron beam commissioning, the issue was the new system processing. We took a lot of time to process the capture section RF structure with and without focusing field, test the FLUX modulator and improve the vacuum etc. After all the systems were well prepared, the first experiment was carried out on March 19, 2005. With help of the new BPMs which is much more sensitive than BCT and two day hard working, we got the first positron beam of 84mA and 48mA at the positron source exit and the linac end, respectively, so the linac transmission efficiency was about 60% as specified.

In a BEPC machine study conducted during April 22 to 24, 2005, a stable 60mA (100mA at the positron source exit), 1.3GeV positron bunch at the linac end has been delivered to storage ring. The primary electron beam was 6.5A, 210MeV with a beam size of about 1.5mm in radius (1σ). Thus, regardless of beam quality, the positron yield of BEPCII positron source is about 7.3% (e^+/e^-.GeV), much higher than the design specification because we got a much smaller primary electron beam size on the target.

SUMMARY

A new electron gun, a new positron source, a new RF power system, 8 new acceleration structures and some modified RF components and a new BPM system for the BEPCII injector linac upgrade are designed, fabricated, tested and installed in their final positions. A satisfied electron beam and positron beam have been preliminary obtained. The positron yield for the positron source was 7.3% (e^+/e^-.GeV), which is much higher than the design goal of 4.3%. The beam emittance measurement and energy spread measurement, especially for the positrons, are now underway.

By further employing the phasing system and beam orbit correction system[6] late on, which are also now underway, we can expect that all beam performance of the upgraded BEPCII-Linac will reach the design goals.

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