UPGRADE STATUS AND COMMISSIONING OF BEPCII LINAC

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Abstract

BEPCII- an upgrade project of the BEPC is a factory type of e^+e^- collider. It requires its injector linac to have higher beam energy (1.89 GeV) for on-energy injection and higher beam current (40 mA e+ beam) for a higher injection rate (≥50 mA/min.). In five months from May 1st of 2004, we've installed and upgraded major parts of the machine, and then it ran for busy BSRF operation. We took very limited time to commission the machine and got a preliminary but satisfied result, the positron beam at the linac end was about 60mA. Now the linac is running smoothly, almost all design goals have been reached. In this paper, we'll present the upgrades for better beam quality, such as phasing system, beam feedback system, and report the present status of the BEPCII linac.

INTRODUCTION

BEPCII[1] is a factory type e^-e^+ collider with 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 (almost twenty times of present number) for e^+ beam requires the existing BEPC injector linac to be upgraded with higher performance[2]. The BEPCII linac design was completed in the year of 2002, and almost all upgrades had been conducted by the end of 2004[3], including 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. The linac control is based on EPICS environment, and 20 BPMs installed in the linac, which much improved the linac performance. We even got the first positron beam of ~50mA at the linac end on March 19th, 2005. The electron beam out of gun was ~10A, and ~ 6A at the positron converter target as simulation predicted. The issues of last linac run from early March to the end of July, 2006 are system commissioning and machine studies for getting better beam quality and solving orbit oscillation. Table 1 lists the most recent BEPCII linac operation results.

Table 1: Recent BEPCII-Linac operation results

Parameters		Goal	Measured
Energy (GeV) (e^+)		1.89	1.89
Current (mA)	e^+	37	60
	e^-	500	>500
Repetition rate (Hz)		50	50
Emittance (1σ) (mm-mrad)	e^+	0.40	0.32
	e^-	0.10	0.09
Energy spread (%)	e^+	±0.50	no measured
	e^-	±0.50	no measured

ELECTRON GUN

The new electron gun is the EIMAC Y796 thermionic triode gun. 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 150-200kV high voltage is provided by a pulsed power supply. At 150kV, we can easily get 12A electron beam from the gun, which agrees very well with simulation result. Figure1 shows the pictures of the new electron gun system (left) and the produced beam pulse (right).

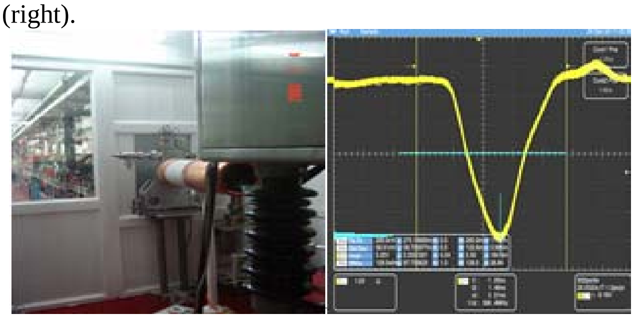

Figure 1: New electron gun system (left) and its produced beam pulse (right).

POSITRON SOURCE

The BEPCII positron source[4] is a conventional source. Electrons are accelerated to 240MeV by pre-injector and booster linac, and focused to a 3-5mm diameter spot on a tungsten target. The target itself is a 10-mm diameter, 8-mm thick disk. The matching device is a SLAC type flux concentrator (FLUX) which is powered by 12kA flux modulator. 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 match 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. Figure 2 is the picture of the BEPCII positron source.

Figure 2: 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. The klystrons used now are two TH-2128C, two SLAC 5045 and 12 E-3730A tubes. All the 16 modulators are rebuilt for 50pps, 360A beam current and 320kV beam voltage operation. The De-Qing circuit will be adopted to keep the beam voltage stability within ±0.15%. Figure 3 is the klystron gallery picture.

Figure 3: Picture of BEPCII klystron gallery.

A new low level RF system is being developed. The maximum energy method is adopted to define the optimum phase, which appears preferable to the beam loading and beam induced methods. The PAD design is based on I/Q demodulator technique, which can detect the RF phase with a resolution of 0.2^o and the amplitude of 0.1%. The new IϕA unit has a 2 dB insertion loss, 20dB maximum attenuation and > 360^o phasing range. The reference line is 7/8in Andrew Heliax phase stabilized co-axial cable. The tough issues for the low level RF system are the EMI and temperature stabilization. After many trials in the klystron gallery, now the phasing system is working properly. The klystron gallery temperature fluctuation is controlled within ±2^{o}C, while the reference line ±0.1^{o}C. Figure 4 shows some pictures of the BEPCII phasing system, and figure 5 is the interface for phasing program (left) and phasing monitor (right).

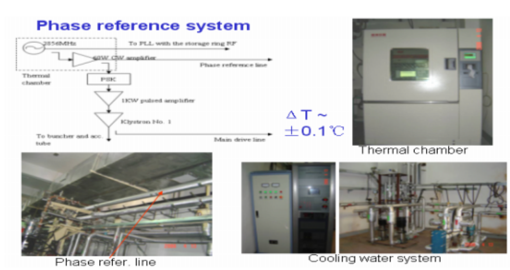

Figure 4: Pictures of the BEPCII phasing system.

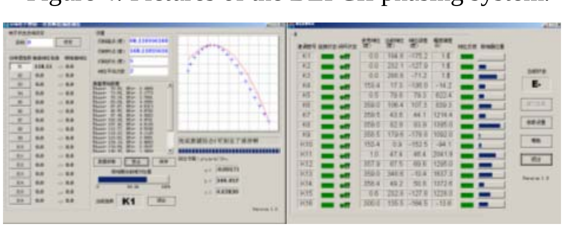

Figure 5: Interface for phasing program (left) and phasing monitor (right).

BEAM OPTICS AND ORBIT CORRECTION

Beam modeling for the BEPCII injector linac has been conducted with a lot of common codes, for example TRASPORT, EGS4, PARMELA and LIAR were used for simulating positron performance at positron production system and transportation at downstream linac. The control software for beam optics and orbit correction is developed in our lab using C^{++} language. The computation results agree very well with TRANSPORT simulation results. The code can be run on the UNIX and LINUX platforms, and the communication with EPICS is completed using EPICS library functions. Levenbery-Marquardt algorithm is adopted for the computation of beam optics matching and orbit correction. This algorithm converges better and the computation is much faster. Global correction method is adopted for orbit correction.

The BPM data is used for the orbit analysis as shown in figure 6. And figure 7 shows a group of 8 hour data at BPM5. These RMS values contain beam orbit oscillation and BPM system errors. BPM system and orbit correction system are now working smoothly. In later section of machine operation we will see that they play a very important rule in machine commissioning, analyzing and solving the beam orbit fluctuations.

There are 20 BPMs in the linac, and at present stage only 4 Bergotz log-ratio electronics are used for signal processing with signal switching system, which is hard to give one-shot beam position information. Later we will install the electronics of BPMs one-by-one. For the two bunch accelerator scheme, the Bergotz BPM circuit is not precise because two signals will over-wrap[5]. So we are considering using a very few oscilloscopes for BPM signal process because the oscilloscope is too expensive.

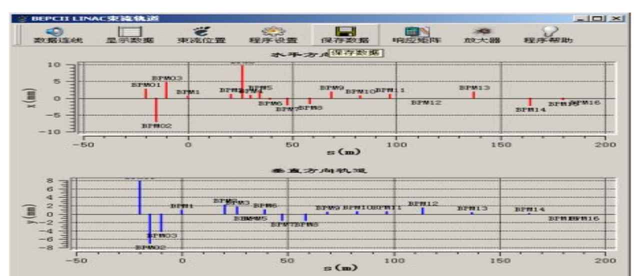

Figure 6: Interface of BEPCII linac BPM system.

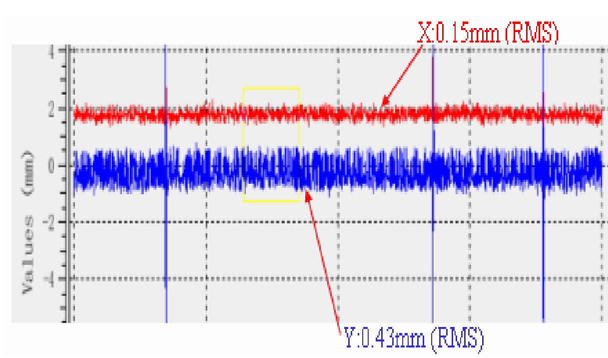

Figure 7: BPM5 data for 8 hours.

OTHER IMPROVEMENTS AND UPGRADES

On July 6 at 2005, we routinely shut down the machine for maintenance and for further upgrades, but found some klystron windows broken. After careful investigations we found that some windows were badly contaminated with (C, Cu, stainless steel etc.). We replaced these tubes, and took many measures to protect this kind of things happen again:

Renew the vacuum system: 60 old ion pumps (70 l/s) and power supplies were replaced, 22 old vacuum gauges replaced by new ones (Belzers), 30 l/s ion pumps added at each klystron output waveguide, and additional 30 l/s ion pumps added only for HP waveguide valves.

Tight klystron protection interlock: Clear and complete regulations for klystron installation and high power process were established, tighter reflection power protection and waveguide vacuum as well as RF structure vacuum protections improved, new data base developed with daily report and weekly report which is very helpful for monitoring and analyzing problems.

The BEPCII bunching system consists of an S-band pre-buncher and a buncher, and beam pulse width from the gun is about 1.6ns (bottom width). So the linac is not single bunch operation, while with one main bunch and some satellite bunches. The satellite bunches are troublesome and make operation not clean, and cause the beam instability. We have started sub-harmonic bunching system R&D, and the design had been approved by the BEPCII headquarter.

Linac timing used as a prototype of whole BEPCII timing system is based on E4434B, MVME5100, EVG-200, EVR-RF-200, EVR-200, TTB, FOUT7, GUNTX, GUNRX, TTL-NIM transition board, TD4V. It now works well in the linac. After synchronization between gun trigger and 2856MHz, the grid pulser jitter was measured to be 16 ps in one sigma to the ring frequency.

BEPCII LINAC OPERATION STATUS

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. The first commissioning results were very close to the parameters listed in table 1 except for the beam stability.

Last run machine operation was scheduled from early March to the end of July, 2006. The issues were positron beam current, positron beam energy as well as emittance. Much time were spent on the new timing system, phasing system and orbit correction system. With BPM data, we found a strong orbit fluctuation to a range of few milimeters which troubled us for months. A lot of correlation experiments were conducted but could not find the sources as shown in figure 8. Figure 8 (up) shows the beam orbit has fast and slow oscillations, and the slow orbit oscillation has close correlation with cooling water emperature of the pre-injector RF structure (figure 8 (down).

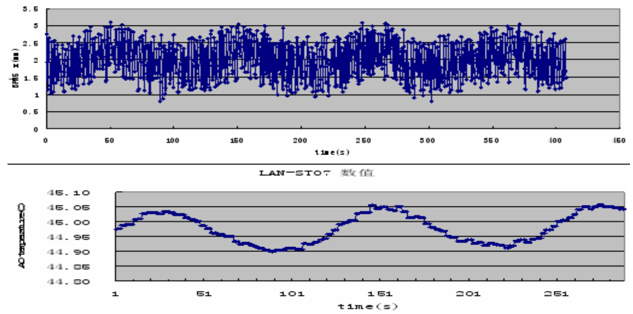

Figure 8: Correlation plot between beam orbit (up) and A_0 temperature (down).

A special mini-workshop[5] was held with KEK experts in July 17-19, 2006. After many trials, a beam test was carried out by synchronizing the 2856 MHz rf frequency with the 499MHz ring rf frequency. The result indicated that the periodical oscillation was greatly reduced with the oscillation amplitude (pk-to-pk) of 1/4 in comparison with the original one, which could be explained as the satellite bunch charge changing and wake field. So the other possible source would be the gun lens misalignment.

SUMMARY

Through four more year hard working, almost all the BEPCII linac design goals have been reached. The positron beam is about 60 mA, 1.9 GeV, 0.3 mm.mrad (1σ). The gun trigger jitter is 16ps (1σ), and orbit jitter at the linac end 0.16mm (1σ).

But, testing and reaching a goal is one thing, long term stable operation with very good beam quality is another story. We'll pay more attention on this issue, keep system improvements and/or upgrades continuously and guarantee a single device to work properly.

The SHB system as one of the second phase upgrades will be sped. The rough schedule is the system will be ready by the end of 2007.

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