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Progress of the Injector Linac Upgrade for the BEPCⅡ Project *

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Abstract BEPCⅡ——an upgrade project of Beijing Electron Positron Collider (BEPC) is a factory type of e^+e^- collider. It requires its injector linac to have a higher beam energy (1.89 GeV) for on-energy injection and a higher beam current (40 mA e^+ beam) for a higher injection rate (50 mA/min). The low beam emittance (1.6π mm·mrad for e^+ beam, and 0.2π mm·mrad for 300 mA e^- beam) and the low beam energy spread (±0.5%) are also required to meet the storage ring acceptance. Thus the original BEPC injector linac must be upgraded to have a new electron gun with its complete tuning system, a new positron source with a flux concentrator, a new RF power system with its phasing loops and a new beam tuning system with orbit correction and optics tuning devices. These new components have been designed, fabricated, tested and will be installed in their final positions in this spring and summer, which are described in this paper.

Key words BEPCⅡ, linac, upgrade

1 Introduction

BEPCⅡ is an upgrade project of Beijing Electron Positron Collider with a high luminosity of $1\times10^{33}\mathrm{cm}^{-2}\cdot\mathrm{s}^{-1}$ in the Tao-Charm energy region of 2—5 GeV in the center of mass. The on-energy injection with a high injection rate of 50 mA/min (ten times the present value) for the e^+ beam requires the present BEPC injector linac to be upgraded for its higher performances as listed in Table 1[1].

Table 1. Beam parameters of the BEPCⅡ-Linac.

	unit	e^- beam	e^+ beam
beam energy	GeV	1.89	1.89
beam current	mA	~40	~300
beam emittance	π mm·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 meet these specifications, a new electron gun with its complete tuning system, a new positron source with a flux concentrator, a new RF power system with its phasing loops and a new beam tuning system with orbit correction and optics tuning devices are required. These new components have been designed, fabricated and will be installed in their final positions in this spring and summer, which are described in this paper. In addition, the beam instrumentation system[2], the control system[3], the RF transmission system[4] and the vacuum system[5] are also upgraded and described in the reference papers. The beam commissioning is expected to start from October of 2004.

2 The electron gun system

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 conventional thermionic triode gun with a cathode-grid assembly of Y796 is adopted with the gun beam parameters of 10 A, 1 ns, 10 nC, 150—200 keV and 50 Hz.

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The computed perveance is 0.22 μP. At the gun exit, the radius of beam is about 6.0 mm, and the emittance is 17.1 πmm·mrad. The beam trajectories show that the current density is relatively uniform, which indicates a good beam performance[6]. The Kentech's pulser is employed, which can be operated at 1ns pulse length of either one pulse or two pulses separated by about 56 ns for the future two-bunch operation based on the two sub-harmonic bunchers[7]. Between the gun exit and the prebuncher, there are two focusing lenses, two steering coils and two BPMs, and a profile monitor for good beam alignment and tuning, as shown in Fig.1.

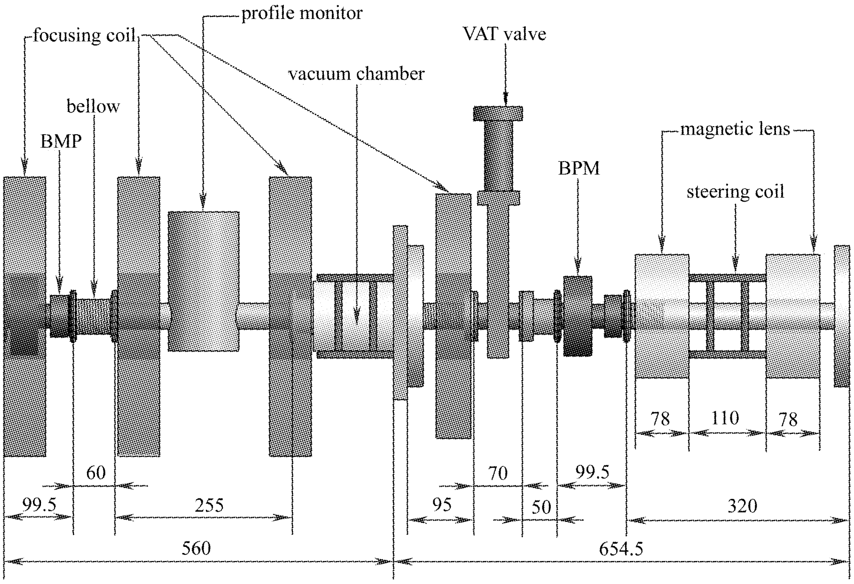

Fig.1. Components downstream the electron gun.

3 The positron source system

A 250 MeV and 6 A primary electron beam at the positron production target is designed. To have a maximum positron production rate, a tungsten target thickness is optimized at 8 mm and a primary electron beam spot size of 1.0—1.5 mm at the target is expected by the beam modeling. A flux concentrator (FC) with 10 cm long is employed to have a maximum transverse acceptance of 0.31π (MeV/c) · cm, which provides a pulsed longitudinal magnetic field of 4.5 T and 0.5 T at the input and output of the FC, respectively, with a 12 kA pulsed power supply. In the downstream of the FC, there is a 7.5 m long DC solenoid with a magnetic field of 0.5 T to further focus the positron beam and to match the beam into the downstream quadrupole focusing system. In addition to the available 15 triplet quads, 24 big aperture quads installed on the downstream accelerating structures will be employed to strongly focus the large emittance positron beam. In order to bunch the beam longitudinally, the positron beam is decelerated in the first 1 m of the structure just downstream the FC, and then soon accelerated with a gradient of higher than 12 MV/m so that most of the positrons are bunched into a phase spread of $\pm 5^0$ at the DC solenoid exit with the positron yield of 4.3% (e^+/e^- .GeV)[8]. The 8 accelerating structures of 3 meters long each in the positron production system will be replaced[4] by the new ones in order to have high stability and reliability in high gradient operation, since some of these structures were a little damaged in the past operation.

All the components of the new positron source have been fabricated, inspected, pre-assembled and vacuum tested. A 12 kA pulsed power supply has been built, and tested with the FC. It works well as expected. The FC has its inductance of 0.95μH, and the measured mechanic resonance frequency 37 Hz as simulation predicted. The measured magnetic fields of the FC are 5.3 T and 0.5 T at the input and output of the FC, respectively, which are satisfied with the design goal. The target chamber has reached a vacuum of 7×10^{-9}Torr, better than the design goal of 5×10^{-8}Torr. Figs.2 and 3 show the pictures of the new positron source. The target positioning system driven by a stepping motor has been tested continously in five days, having more than 7000 times of stable and correct target positioning$^{1)}$.

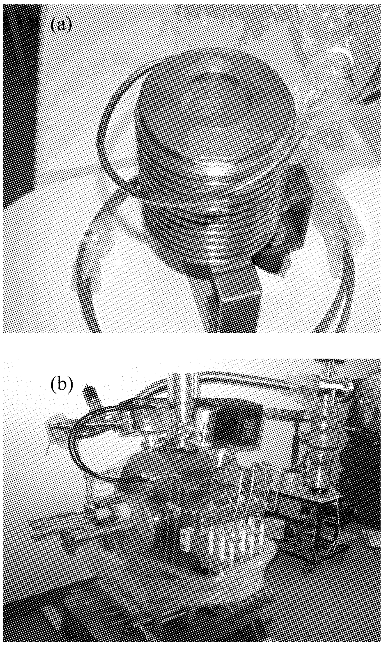

Fig. 2. The flux concentrator (a) and positron converter chamber (b).

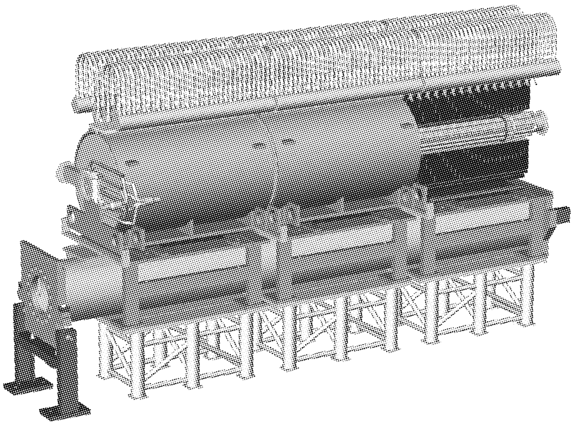

Fig. 3. The positron focusing and accelerating system.

4 RF power supply system

There are 16 klystron units in the linac. Downstream the positron source there are 12 regular acceleration sections, i.e. one klystron drives four SLAC type acceleration structures with a SLED. To increase the positron energy from the current 1.3—1.5 GeV to 1.89 GeV and to increase the primary electron beam energy for a higher positron yield, the RF power supply system must be upgraded to have higher power and higher stability. Therefore 50 MW klystrons are needed to replace the original 30 MW HK-1 klystrons. All the 16 modulators will be rebuilt for 50 pps, 360 A beam current and 320 kV beam voltage with a target stability of ±0.1% provided by a De-Qing system. The pulse waveform is as shown in Fig. 4. In the total 16 klystrons, there are three TH-2128C (45 MW), two SLAC-5045 (65 MW) and eleven E-3730A (50 MW). A new klystron test stand has been built, and two new klystrons/modulators have been put into operation.

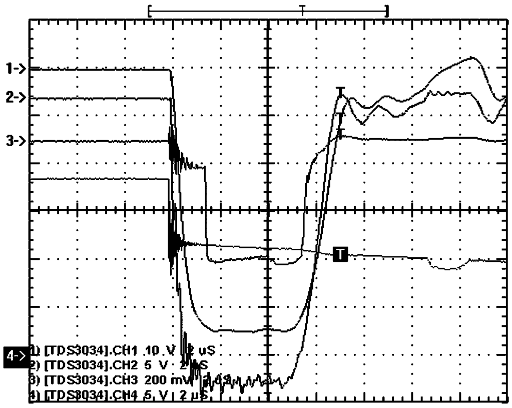

Fig. 4. The modulator's pulse waveform.
1) beam voltage; 2) beam current; 3) RF output.

5 The phase control system

A phasing system is being developed with the following measures[9]. The maximum energy method is adopt to define the optimum phase, which appears preferable to the beam loading and beam induced methods. A phase and amplitude detector (PAD) system of I/Q demodulator type is used to monitor the phase with accuracy of 0.2° and amplitude. The new IφA units, which are the executive devices to adjust the phase and amplitude, have been developed with its minimum insertion loss of 2 dB, maximum decay of 20 dB and phasing range of >360°. A reference line of the phase stabilized co-axial type is employed for its easy maintenance and cheaper than the optical type. The existing co-axial driving line can be further used by controlling the cooling water temperature within ±0.1℃. A master oscillator with high stability of phase and output power is demanded. To have the effective phasing system development, many measured data have been taken in the existing RF system, including the phase variation

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with the temperature, with the electric and magnetic noise, etc. A prototype of the phase control system was made for the 1st RF unit, and a very good experimental result of this control unit has been obtained with the phase control within ± 2° Fig. 5 shows the BEPCⅡ-linac phasing system and its constitutions. The parameters of the key components are listed in Table 2.

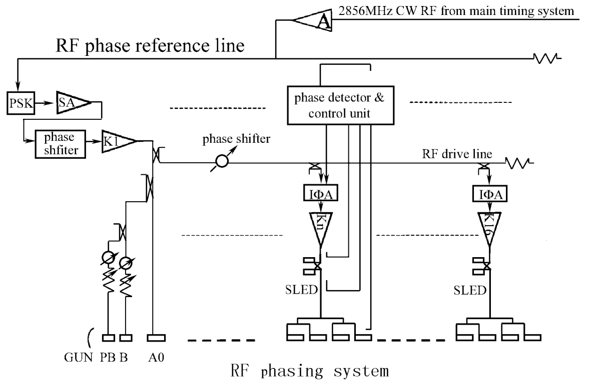

Fig. 5. The BEPCⅡ-Linac phasing system.

Table 2. The parameters of the key components.

components	
phase stability of reference line	0.3°
PAD phase resolution	1°
PAD amplitude resolution	±0.1%
IφA phase resolution	1°
reference line temperature stability	±0.1℃
driving line temperature stability	±0.1℃

6 Beam modeling

Positron beam simulations. With TRASPORT, EGS4, PARMELA and LIAR codes, the e^+ beam performance at the production target and its transportation in the linac are simulated. Table 3 shows that about 40mA e^+ beam with specified emittance and energy spread is expected. The 24 large aperture quads "riding" on the acceleration structures are needed to improve the transmission for the larger emittance positrons out of the focusing solenoid. The beam initial offset of 0.3 mm, and 0.2 mm misalignment (1σ) of RF structures and quads are taken into account. The orbit correction provided by 19 strip-line BPMs and 19 sets of correctors is needed to meet the design goal of the beam performance.

Table 3. Simulation results for the e^+ beam.

posit.	energy /MeV	current /mA	emittance /πmm·mrad	$\Delta E/E$ (%)	phase spread /(°)	e^+ yield /(e^+/e^-.GeV)
target	1—14	80	3080	—	—	5.58%
solenoid exit	89.45	53	29.2	±8.6%	±16	3.67%
linac -end	1890	42	1.42	±0.5 %	±5.0	2.92%

Electron beam simulations. With EGUN, TRANSPORT, PARMELA and LIAR codes, the electron beam performances are simulated and are listed in Table 4 and Table 5. The 1.89 GeV electron beam with small emittance and energy spread is not a problem, but the primary electron beam size on the converter target is a big issue because it's very important for positron production. A beam size of less than 1.5 mm is suggested in the design, and the confinement mainly comes from the quads chromaticity due to the low energy (250 MeV) and the large energy spread caused by the bunching system. The other contributions come from the dispersive effect and wakefield effect caused by the initial beam offset and machine misalignments. The orbit correction system is also needed to meet the design goal of the beam performance.

Table 4. Simulation results for the e^- beam.

posit.	energy /MeV	current /A	emittance /πmm·mrad	$\Delta E/E$ (%)	phase spread/(°)
gun exit	0.150	1.5	42.5	—	±180
pre-injector	39	1.0	4.14	±1.5%	±5
linac-end	1890	0.6	0.18	±0.5 %	±5

Table 5. Simulation results for the primary e^- beam at target.

posit.	energy /MeV	current /A	emittance /πmm·mrad	beam radius /mm
gun exit	0.150	10.0	17.1×10^{-6}	6.5
pre-injector	40	6.5	2.79×10^{-6}	3.4
on target	1890	6.0	0.75×10^{-6}	1.0—1.5

7 Summary

1) A new electron gun, a new positron source, a new RF power system with phasing loops and 8 new acceleration

sections for the upgraded BEPCⅡ injector linac are well designed, fabricated, tested and will be installed in their final positions in this spring and summer. A higher performance electron and positron beam from this linac is expected by this fall.

2) By controlling the phasing error within ±2°, Quads/BPM/structure's alignment error within ±0.2 mm, and modulator's voltage errors within ±0.1%, the beam performance at the linac exit can meet the design goal with the orbit correction system[10].

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BEPCⅡ直线注入器重大改进进展*

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摘要 BEPC Ⅱ是“工厂”型的高亮度正负电子对撞机.它要求其直线注入器提供高能(1.89 GeV)和强流(40 mA e^+,300 mA e^-)的正负电子束以实现全能量注入和高注入速率(50 mA/min. e^+),并要求直线注入器出口正负电子束的发射度低(1.6πmm·mrad e^+, 0.2πmm·mrad e^-)、能散小(±0.5%)以满足储存环接受度的要求.因此,必须对现有BEPC的直线注入器作重大改进,包括新电子枪及其束流调整系统、新正电子源及其磁号装置、新微波功率源及其相位控制系统、新的束流轨道和光路调整系统等.这些新系统和装置大多已完成了设计、研制、测试和试组装等,将在今年的春夏安装于隧道,并期望在年底前获得正负电子束.

关键词 BEPCⅡ 电子直线加速器 重大改进

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* BEPCⅡ重大改进工程项目

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