Current Status of BEPC

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Introduction

BEPC(Beijing Electron Positron Collider) is the first high energy particle accelerator ever built in China. It consists of four main subsystems: a 1.4-1.55 GeV eletron positron linac, a 2.2-2.8 GeV storage ring, a magnetic spectrometer for high energy physics experiments, and synchrotron radiation facilities. The designed luminosity is 1.7 X $10^{31}cm^{-2}sec^{-1}$. The total budget is 240 million Chinese Yuan (RMB), which is equivalent to about 80 million US dollars in 1984. It was approved by the government in April 1983 and is scheduled to be completed by the end of 1988.

There are two purposes for building such a collider. The first one is to do particle physics research, such as charmed particle physics and lepton physics, the second one is to provide synchrotron radiation in VUV,soft-ray and hard-ray for scientific research and applications in other sciences.

So far the tunnels for the electron linac and the storage ring and the experimental halls have all been completed. The experimental halls for synchrotron radiation will be available for installation in the middle of this year. Most of the conventional facilities have been installed and put into operation. As to the components of the collider, great progress had been made in developing the prototypes in 1985 and batch production started in 1986. Up to now, most of them have been fabricated, tested and installed in tunnels with the exception of R.F. cavity and wiggler magnets. Tests showed that their performances have reached the designed requirements. The installation of the transport lines,the electron linac and the storage ring were completed in June, September and October last year respectively. Beam commissioning of the linac was carried out at the end of last October and an electron beam with the energy of 1.17 GeV and an intensity of 240 mA was produced from the linac on December 5 last year. Beam commissioning of the storage ting started on December 8, 1987. After four hours'adjustment in the morning of December 17,the beam turned around the ring more than 5 turns without the addition of R.F. cavity. Most of the I&C hardwares and softwares have been tested, assembled and debugged, and the system assembly and connection to the equipment are underway.

Linac

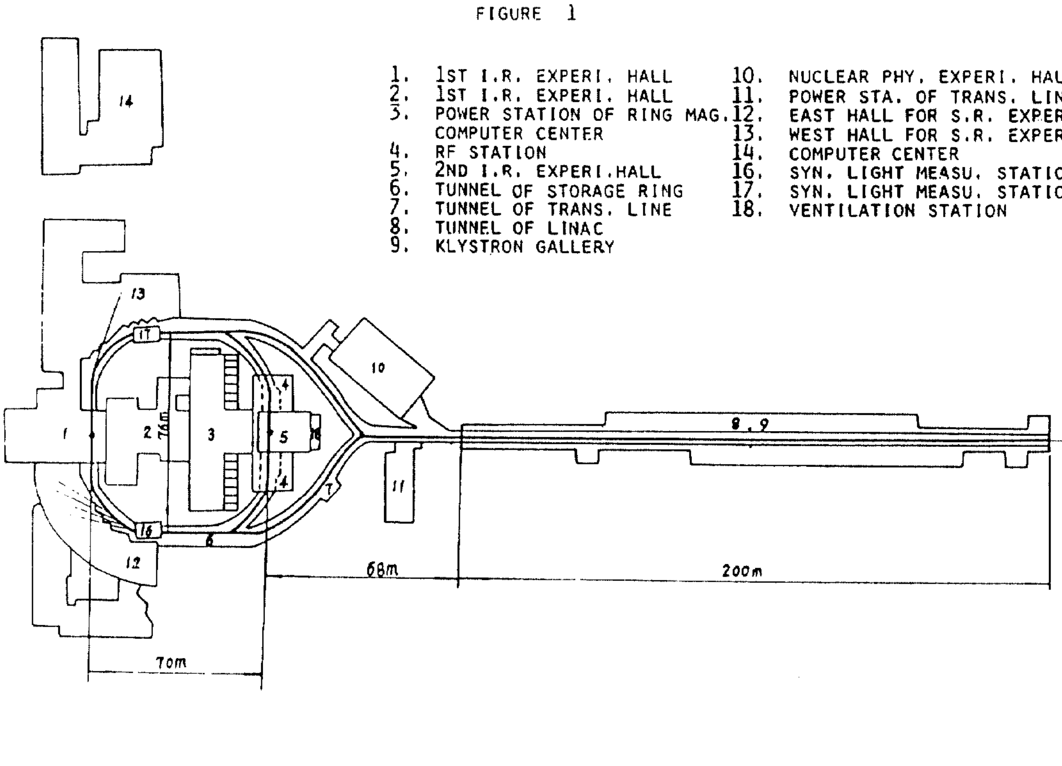
Figure 1 is a layout of the BEPC project. Table one shows the main parameters of the electron linac.

Table 1

$e^{\pm}$ energy	1.4 - 1.5 GeV
pulse electron current	0.2 - 2 A
pulse width	2.5 ns
pulse repetition rate	50 times/sec
number of klystrons	16
klystron power	20 MW
number of accele. tubes	56
working frequency	2856 MHZ
energy spread E/E	±0.6%
bunch phase spread	5°
energy preinjector	30 MeV
bombarding energy for positron production	150 MeV
thickness of positron production target	5 mm
emittance of positron beam	0.22 MeV/c.cm
positron production rate	0.02 e^+/e^- GeV

Compared with the data published in 1983 (1), the major modification according to paper (2) lies in the shift of the positron production target from 340MeV to 150MeV with the total length of the linac unchanged. Besides, thanks to the successful development of the 30MW klystron, the output energy of the electron linac can reach 1.4-1.55 GeV, thus full energy injection may be possible when physics is done in the region of

FIGURE 1



1.55GeV.

1). Main components of the linac

56 disk-loaded wave guides were fabricated in-house. A dedicated production line was established in 1985 with a special large hydrogen furnace. A 3.05m long disk-loaded wave guide can be brazed in full length in the furnace. The monthly output is 6. By the end of 1986, all the accelerating tubes had been finished and adjusted. Test showed that only 3 did not meet the designed parameters. In a 3.05m long accelerating tube, the maximum phase shift between cavities is 2.5°, attenuation constant is 5db, and the standing-wave ratio is < 1.2 when the band width is 4.5MHz. Besides, the prebuncher, the four-cavity buncher with a phase shift speed of 0.75c, the focusing coil for the first accelerating tube , the target, the pulse flux concentrator of positron source, etc. have all been manufactured and installed. 14 pieces of the energy doublers were fabricated in-house with Q = 95000. 16 klystrons and the modulators have been manufactured, the output power of each klystron has reached 30MW in testing stage. For parameters, see Table 2.

Table 2 Measured result of klystron

pulse voltage	250KV
pulse current	265A
perviance	2.14P
pulse drive power	164W
average output power	3.78KW
pulse output power	30.6MW
gain	52.76db
efficiency	45.7%

2). Installation and commissioning

In order to find out problems that may emerge from the key components by putting them under system integration test and checking positron production and positron acceleration, installation of the linac was conducted in two ateps. The first step was to install the first 250MeV section and at the same time, to set up the auxiliary equipments necessary for the commissioning of the 250MeV section, such as water, electricity, heating and ventilation. The second step was to carry out in turn the commissioning of the 250MeV section and the installation of the rest of the linac which started from the way back to the 250MeV section.

The installation of the 250MeV section started from May last year and soon a lot of difficulties were encountered, such as the high humidity in summer in the tunnel, problems concerning the TIG welding between flanges of the accelerating tubes, etc. It was just because of this that the installation of the 250 MeV section was not finished until the end of 1986. And it was not put in trial operation until February lasr year because the conventional facilities were unavailable.

The 250MeV section had been commissioned four times which amounted to 60 days and nights during the period from February to May last year. Finally, 100MeV positron with beam intensity 2.5mA has been obtained. The main parameters are shown in Table 3.

Table 3

pulse beam current of electron gun	0.92A
bombarding electron beam current	785mA
bombarding electron energy	148MeV
bombarding beam diameter	2.5mm
positron beam current	2.5mA
positron beam energy	99MeV
electron beam energy	250MeV
positron production rate	0.021(e^+/e^--GeV)

The commissioning of the whole linac started from October last year. We also succeeded in accelerating an electron beam with the energy of 1.17GeV, intensity of 240mA and energy spread ±1% in the linac on December 5 last year. The output current from the electron gun was 640mA. Most of the beam was lost before 150MeV section. There are two reasons for the electron energy less than 1.4GeV. Firstly, as we did not have enough standby klystrons, the maximum power of klystron had to be limited to 20MW in the initial phase of commissioning. When the 1.17GeV was reached, the maximum output power of most klystrons each was between 12MW and 20MW. Three of them could not exceed 2MW. This was caused arcing inside the wave guide transmission line near the coupler of accelerator tube. Later paper balls were found in the wave guides. They were left behind during the installation because of the carelessness of the workers. Secondly, the water flow of constant temperature was insufficient in energy doublers, which incurred temperature fluctuation between energy doubler more than ±0.5C°. Thus the energy multiplification factor (M) was between 1.1 - 1.4. Efforts have been made to improve the water system.

Storage ring

The main parameters of the storage ring are given in Table 4.

All of the components of the storage ring have been tested and installed in the tunnel with the exception of one R.F. cavity and four emittance control wiggler magnets.

1). The magnet system

The storage ring consists of 40 dipoles, 60 quadrupoles and 8 insertion quadrupoles. All the cores are made of stacked laminations. Each lamination is 0.5mm in thickness. The cross-section of a dipole is of C type. For easier fabrication, the curved core has been changed to a straight core, and thus the horizontal aperture is 150mm, 30mm is sagitta and the vertical aperture is 70mm. The bending magnets were manufactured by a factory in Shanghai. By using 5 long coils existent in parallel in the air gap,the integral field distribution of the dipole can be obtained along the radial direction. The integral field discrepancy between bending magnets ($\Delta BL/BL \leqslant \pm 3X10^{-4}$) is better than what theory requires.

The first die for making quadrupole laminations was manufactured by US industry with the arrangement of FNAL, and the second one was made by our machine shop. The quadrupoles were fabricated in-house. Measurements show the discrepancy is $\Delta GL/GL \leqslant \pm 6X10^{-4}$ which is also better than the requirements. 8 insertion magnets were manufactured by Hitachi with the arrangement of KEK, and the field measurement and shimming were first made at KEK with the help of our Japanese friends and were later reshimmed at our Institute. Finally we have got $\Delta GL/GL \leqslant \pm 6X10^{-4}$. Testing of the wiggler magnets is underway.

2). The R.F. system

Owing to the available technology in China at the time of designing (1982 - 1983), 200MHz had to be chosen for the RF system. It consists of two cavities, each of them is powered by four 30KW transmitters. In developing the RF system, we have encountered a lot of difficulties. In the beginning, because of the technique limitations, the input window of the cavity was made of 95 ceramic and the antimultifactor coating technique was not adopted. In addition, there is no cooling water around the window. As a result, the window was broken when 60KW power was input into the cavity. Some measures were taken to solve the problem.

Table 4

energy	1.6-2.8(1-2.8)*GeV
circumference	240m
luminosity at 2.8GeV	$1.7X10^{31}cm^{-2}s^{-1}$
current	37-65 (150)*mA
particles/beam	$3.3X10^{11}(7.4X10^{11})^*$
free length for experiment	5m
number of I.R.	2
revolution frequency	1.274MHz
No. bunches/beam	$1(1-160)^*$
No. of bending mag.	40
No. of quadrupoles	68
max. magnetic field	9028Gs
bending radius	10.345m
frequency of acc.field	199.53MHz
total RF power	200KW
peak RF voltage	1.35 (1.0)*MV
syn. rad. power/beam	2-34 (1.9-78)*KW
syn. rad. loss/turn	522KeV
hori. & verti. tune	$6.18-7.12(7.76-6.76)^*$
hori.&verti. chromaticity	-11.2- -17.7 $(-10.6- -7.9)^*$
hori.&verti. emittance	$0.66(0.03-0.12)^*$ mm.mrad
max. momentum dispersion	$3.9\ (1.4)^*m$
coupling coef.	$0.027\ (o.316)^*$
trans. damping time	8.6ms
overall beam lifetime	6.7 hr
I.R. hori.&verti. beta	1.3m, 0.1m
max. hori.&verti. beta	49.7 (17.4)*m $71\ (15.4)^*m$
hori.&verti. I.R. r.m.s.beam size	0.89mm, 0.069mm
r.m.s. energy spread	$7.4X10^{-4}$
r.m.s. bunch length	$5.8(1.8-4.5)^*cm$
central brightness	$10^{11}-10^{12}\ (4.3X10^{13})^*$ (photons/s.mm.mrad.1%BW)
characteristic wavelength	$14.1-2.63(43.7-2.63)^*$ A°

$(\ )^*$ dedicated mode for synchrotron radiation

We imported from the US 99 ceramic and with it we succeeded in making a ceramic window with cooling water tube and sputtered with 100 Å TIN last June. Besides, a new testing cavity with more effective cooling water jacket and improved with cleaning technology was produced with vacuum reaching $5X10^{-10}$Torr. The ageing conditions for the cavity were also improved. After 20 days' ageing, the continuous power of 25KW was successfully input into the cavity on January 18, 1988, the rising temperature of the ceramic window was less than 15C° which can basically meet the requirement for the commissioning to be conducted last May. It has been decided that this testing cavity is to be installed in the storage ring for the sake of the commissioning and that higher power test will be conducted on the other two cavities later.

In order to quicken R&D of the ceramic windows, a special group was set up to tackle this problem and at the same time, SLAC was asked to help manufacture two ceramic windows. 8 RF transmitters have already been in place, but the test of them one by one did not start until June last year because of unavailable electicity and cooling water. Combining test of the 4 RF transmitters on the west side was made at the end of last year and its output power was provided to the above testing cavity for ageing experiment, the combining test of the other 4 RF transmitters on the east side was finished in April this year, which will be used as a power source for commissioning.

3). The vacuum system

After the Al vacuum chambers extruded by a U.S. manufacturer were shipped to China, the pumping hole, the bending and the welding were done by Chinese industry. When the cleaning of these chambers was finished in-house, the distributed ion pumps made of stainless steel and Ti pieces were installed in the DIP chamber, and the beam position monitors and synchrotron radiation masks were welded in the beam chamber. All of the chambers have been finished and pumped down to 10^{-10} Torr. One section of 7m long vacuum chamber has been installed inside the dipole gap. Vacuum test with the distributed pumps showed that the vacuum reached $3X10^{-10}$ Torr when the magnetic field was between 5000 to 9000Gs, and that the pumping speed could reach 200l/s.m which has met the designed specification when the vacuum was 10^{-8} Torr.

4). The injection system

The main components of the injection system, such as the Lambertson magnets, the electrostatic separators and kickers have all been delivered and measured. The field uniformity in the good field region of the Lambertson magnets is better than $2X10^{-3}$ and the leakage field is about $1X10^{-3}$.

The thickness of the Lambertson septum is less than 7mm. The current stability of its high precision power supply has reached $1X10^{-4}$.

High vacuum test of 5 electrostatic separators has been made, which showed that the vacuum reached $6X10^{-10}$ Torr. Analysis of the residue gas indicated that it was in full agreement with the requirement of the high vacuum of the storage ring. High voltage applied has reached 60KV. The current stability of the power supply for electrostatic separators during long time operation has reached $5X10^{-4}$ /24 hours.

Six kickers have undergone high vacuum test and pulse field measurement. High vacuum test showed that the vacuum has reached the same level as that of the electrostatic separators. Field measurement showed that the field uniformity is $2X10^{-2}$ within 50mm of the median plane of the deflection plate. The discharging circuit of the pulse power supply has been adjusted. The rise time of the rectangular wave form is 200ns, the fall time 400ns and the top width 300ns.

5). Installation and commissioning

Before the first half of last year, the precision measurement and adjustment of the lapped-strengthened triangular configuration survey network of the ring tunnel had been completed, and the precise coordinate of each control point provided.

The installation of ring magnets was carried out in two steps, with the co-girder structure used, magnets were prealigned relatively and precisely cell by cell outside the tunnel and then moved into the tunnel. This has greatly shortened the time for installation of the storage ring.

All of the magnets, vacuum chambers and other beam components (approximately 700 pieces) had been installed and precisely positioned by the end of Novmber last year, and followed by subsystem integration test. The alignment precision of the quadrupoles was $\leqslant$ 0.2mm in both horizontal and vertical direction. The vacuum of the whole ring has reached 10^{-8} Torr from atmosphere without bake-out for only one week. So, it was ready for testing the first beam running in the ring before December 12 last year. After bake-out of the vacuum chambers with temperatures between 100-150C° in March, most of the vacuum parts of the ring have reached $5X10^{-10}$ Torr. Beam commissioning of the storage ring by using the 1.17GeV electron beam output from the linac started on December 8 last year. The beam easily reached the end of the transport line after two hours' minor adjustment. With 8 profile monitors and 3 γ-ray beam loss monitors temporarily installed, we succeeded in injecting the beam into the storage ring on December 17, 1987. The beam coasted around the BEPC for five turns when RF cavity was not applied. As there were no other monitors, not much information about the beam was obtained. The result obtained so far can only testify the normal operation of various systems with the exception of the RF cavity. It is expected that recommissioning will be carried out with the addition of a RF cavity and relevant monitors in May.

6). Instrumentation and control

The design of the BEPC control system was developed on the basis of the SPEAR new control system. One VAX 11/750 was used as the main control computer with a 6 M Byte memory, a 912 M Byte disk and 3 control consoles. Each console is composed of graphics display, touch panels and programmable knobs. A VAX-CAMAC Channel (VCC) with data transmitted by serial optical fibres is used in this data acquisition and processing system. The VCC is an interface designed by SLAC and used at VAX computers for the CAMAC system. There are about 350 CAMAC modules and 700 interface modules connected to about 900 equipments and devices of the collider, such as the magnet power supply, the vacuum system, the RF transmitter and the beam diagnostic system.

The VAX-VCC-CAMAC system had been established by the end of 1986. The technologies concerning hardware or software of the serial optical fibre communication, the console graphic display, the real-time data-base and the BEPC operating system have well been established. Computer controlled on & off operations of 172 power supplies of various kinds were completed and the synchronous RAMP with an accuracy of $2X10^{-5}$ and 8000-16000 steps made. Thus, a set of software system for BEPC power supplies has been established.

The closed orbit measurement of hardware system has been made and the software system of BPM debugged. The systems can collect data, sample ns signals from 128 buttons of 32 position monitors, correct the errors quickly and then display on screen the distortion of the closed orbit of the beam.

In addition, all the control racks, crates and consoles in the local station and the main control room have been in place. A working control station with minimum control function was provided for the commissioning of BEPC at the end of last year.

The timing system was designed on the basis of that for the storage ring at KEK. With the help of KEK's experts, 150 kinds of modules and interfaces were purchased and jitter was measured at KEK. The jitter time is 200PS which met the requirement of timing during the operation of the collider. This timing system was partially operated for commissioning last year.

As for the beam diagnostic system, the closed orbit distortion display system, the synchrotron radiation light monitor, DCCT transformer and beam scrapper, etc., they have all been completed.

Conclusion

Since 1984 when the detailed design was approved, about 3 years have passed, and the BEPC project has progressed quite well. It is expected to be cpmpleted on schedule and within budget.

Acknowdgement

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