BEIJING e^+e^- COLLIDER(BEPC)

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Introduction

According to the policy of readjustment, reconstruction, consolidation and improvment of our national economy, we can get only limited investment for the high energy physics research. After many discussions, we decided finally to build an e^+e^- collider of 2.2/2.8 GeV as our first high energy accelerator. The plan was approved in April 1983. The primary purpose of BEPC construction is for collider physics research. As a first step in our experimental efforts, the emphasis will be put on charmed meson and heavy lepton physics. Later we will do some work on charmed baryons. The storage ring can also provide, either parasitically or part time dedicatedly, synchrotron radiation as vacuum ultra violet and X-ray source. In BEPC, when operated at 2.8 GeV, for the case of 9 kG bending magnetic field the critical energy of the radiation spectrum is 4.7 keV with usable range of about 0.47eV—23 keV and at second step for 50 kG wiggler magnet, the critical energy is 26 keV and the usable range is 2.6 eV—130 keV.

The accelerator consists of injector, beam transport system and storage ring. At the collision point a magnetic spectrometer-type detector is located. The general layout of BEPC is shown in Fig.1.

The preliminary design has been completed and the technical design is still in progress. It is expected to complete this project in 1988.

A preinjector of the prototype which may accelerate electrons to 30 MeV is just being put into operation. The manufacture of prototypes of various magnets, RF cavity, injection elements, power supplies, monitors and RF station are in progress also.

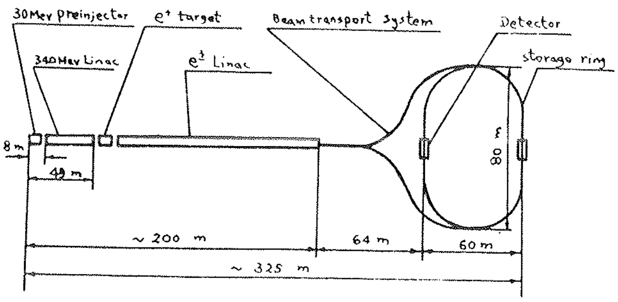

Fig.1. The general layout of BEPC

Injector linac

A travelling wave electron linac is to be built as the e^+e^- injector of BEPC. The system contains a preinjector followed by 340 MeV electron linac, a positron source and the main e^+e^- linac. The main design parameters of the injector linac are as follows:

e^+e^- energy (MeV)	$1.1 \leq E \leq 1.4$
Beam current (A)	1—2 (for positron production)
	0.2 (for electron injection)
Beam pulse duration (ns)	2.5
Pulse repetition rate (pps)	50 max.
RF pulse width (μs)	3
Number of klystrons	16
Operating freqency (MHz)	2856
Number of accelerating sections	56
Total length of the injector (m)	200

A block diagram of the injector linac is shown in Fig. 2.

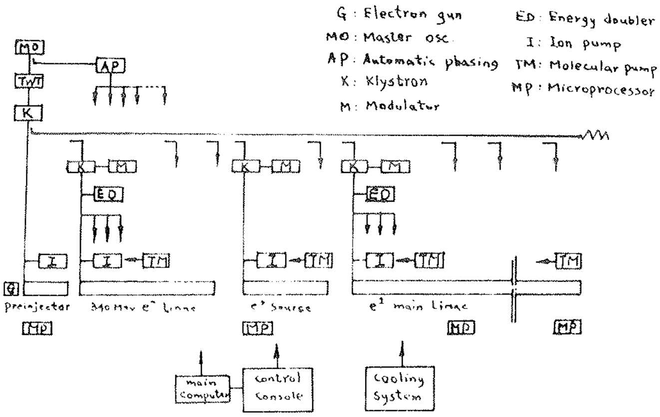

Fig. 2. Block Diagram of the Injector Linac

Preinjector:
The preinjector consists of the electron gun, a prebuncher and a four-cavity buncher (β=0.75), a 3.05m long accelerating section and the focusing system. Electrons will be accelerated to an energy of 30 MeV in the preinjector.

Electron gun:
A triode-type electron gun will be used to produce the 2.5ns electron pulse. The pulse current would be in first step 1 A and in second step would reach 3-4 A to produce enough positrons to shorten the injection time. -80 kV DC voltage will be applied to the gun and the electron emission will be controlled by a grid pulse from an avalanche fast pulser.

Standard accelerating section:
The standard accelerating section is a 3.05m long constant gradiant disc-loaded waveguide operated at $2\pi/3$ mode and 2856 MHz. OFHC copper ring-disc structure will be adopted. Each section will have 86 cavities.

Power sources:
The microwave power for acceleration will be delivered from 16 KMF-1017 type 5-cavity klystron amplifiers offered by our industry. Each klystron may give an output of 15-20 MW pulsed power and will feed power to 4 accelerating sections. A line-type 250 kV pulse modulator is provided for each klystron. One of the klystrons which feeds the preinjector will give its surplus power to drive other klystrons. This klystron will be

drived by a TWT amplifier. A crystal oscillator is used as the master oscillator.

Microwave system:

A 50 Ω rigid coaxial line will serve as the phase stable drive line.

High power outputed from the klystrons will be transmitted via standard rectangular waveguide system to the accelerating sections. In order to save some klystron stations, microwave energy doublers of the SLED type will be used to enhance the peak accelerating field.

For maintaining correct phase relations between waves and electrons, an automatical phasing system will be used and the waveguides which feed the four accelerator sections from each klystron will be designed and calibrated after assembly for equal electrical lengths.

Positron source:

The positron source is made up of tungsten target, flux concentrator, 2 sections of standard accelerator sections, 6 meters long uniform solenoid, bending magnet and RF separator. 370 MeV electrons will strike the target and the positron production will be 0.025 e^+/e^- GeV.

Vaccum system:

Requirements to the vaccum system are: inside the accelerator 5×10^{-7} torr; in the vicinity of the klystron output window 5×10^{-8} torr. At the input waveguide of each section there will be a 30 1/s diode sputter ion pump. Some turbomolecular pumps of 450 1/s are to be provided for rough pumping.

Cooling:

Requirements have been proposed to various parts:

for accelerating structures	45°C±0.1°C
for rectangular waveguides	45°C±1°C
for energy doublers	45°C±0.3°C
for klystrons	35°C±0.5°C

Control and instrumentation:

A two-stage computer controlling will be adopted. Several microprocessors served as front-end computer and a main computer will be used for the linac.

Monitors measuring beam position, profile, intensity and other beam parameters are to be mounted at 15 drift spaces along the linac.

Building:

The ceiling of the 3x3 m^2 cross-sectional accelerator tunnel is 4 meters underneath the earth. The underground arrangement facilitates the shielding problem. The main equipment gallery is on the ground above the tunnel.

Beam transport system

The beam transport system between the exit of linac and the injection point of the storage ring is shown in Fig. 1. It consists of a trunk and two symmetrical branches. The length of the trunk is 33 m. The first 16 m section is reserved for further development such as extracting the linac beam for nuclear experiments.

The first horizontal bending section of each branch consists of eight bending magnets and five quadrupoles. It is an achromatic section and deflects the beam 60°. The second horizontal bending section is similar to the first but it deflects -60°. The last section of each branch is an achromatic vertical bending section. It deflects the beam up by 8° to raise its height to 2.97 m, then the last element of the branch——the Lambertson magnet bends the beam by -8° to reach the level of the storage ring at the injection point. The beam will be injected from inside of the ring.

The whole transport system consists of 35 bending magnets and 48 quadrupoles. The bending magnets are powered by 4 separated supplies. The quadrupoles are divided into 16 groups and are powered by separated power supplies.

Storage ring

General design considerations:

The storage ring which resembles a racetrack has a circumference of 238.4 m. There are two experimental areas with 5 m long interaction region. It has been designed to optimize the luminosity at 2.8 GeV. At the nominal energy the calculated peak luminosity is about 1.7×10^{31} $cm^{-2}sec^{-1}$, corresponding to the beam-beam space charge parameter as 0.04. Between 2.2 and 2.8 GeV, wiggler magnets will be used to keep the horizontal emittance constant. So at 2.2 GeV the calculated peak luminosity is $1.0\times10^{31}cm^{-2}sec^{-1}$.

A separated function FODO lattice has been adopted. The schematic layout of the lattice and structure functions in a quadrant is shown in Fig. 3 and Fig. 4 respectively. Each regular cell is 6.6 m long and contains two quadrupoles of 0.4 m each as well as two bending magnets of 1.6 m each. Between the Q and B, there are short straight sections for the arrangement of vacuum pumps, position monitors, sextupoles and horizontal field trim dipoles. The main parameters of BEPC are given in Table 1.

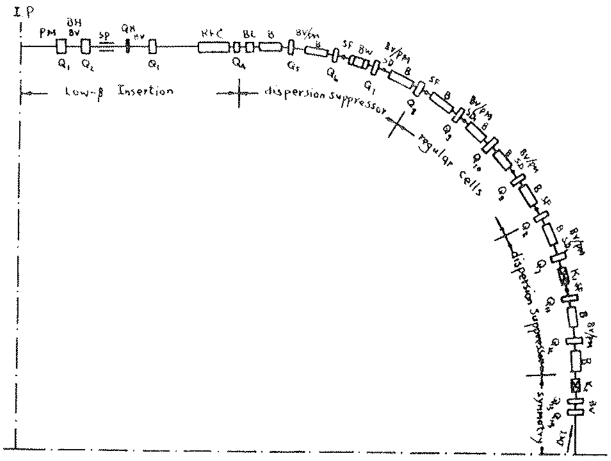

Fig.3. Schematic Layout of Storage Ring Lattice in a Quadrant

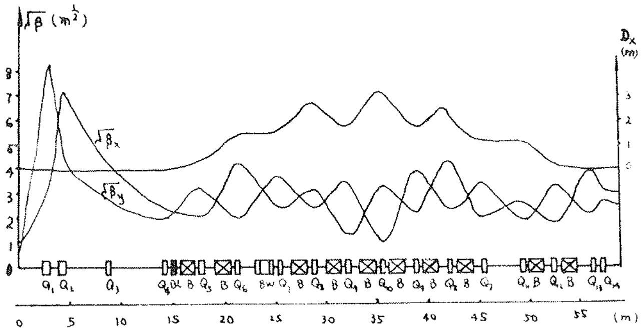

Fig. 4. Betatron Function β_x, β_y and Dispersion Function D_x in a Quadrant

Table 1. Main parameters of BEPC[1]

Energy	2.8 GeV
Number of interaction regions	2
Free length for experiments	2.5 m
Number of bunches per beam	1
Circumference	238.4 m
Bending radius	10.34 m
Horizontal betatron tune	6.28
Vertical betatron tune	7.12
Revolution frequency	1.2575 MHz
Circulating current per beam	66 ma
Number of particles per bunch	3.3×10^{11}
Transverse damping time	8.5 ms
Horizontal chromaticity	-12.315
Vertical chromaticity	-19.187
Natural RMS energy spread	7.4×10^{-4}
Natural RMS bunch length	5.1 cm
Uncoupled horizontal emittance	0.67 mm.mrad
Designed coupling coefficient	0.27735
Horizontal emittance with designed coupling	0.62 mm.mrad
Vertical emittance with designed coupling	0.048mm.mrad
Beam-beam Bremsstrahlung life time	9.0 h.
Touschek lifetime	50.6 h.
Quantum lifetime	56.9 h.
Over all lifetime	6.7 h.
RF frequency	201.2 MHz
Synchrotron radiation loss/turn	521.5 keV
Synchrotron radiation power (two beams)	69 kW
Fundamental mode RF dissipation	97 kW
Total RF power	200 kW
Synchrotron oscillation tune	0.02011
Momentum compaction factor	0.036492
Max. horizontal beta function	50.59 m
Max. vertical beta function	64.53 m
Max. momentum dispersion	3.02 m
Vertical beta function at interaction point	0.1 m
Horizontal beta function at interaction point	1.3 m
Vertical linear tune shift per interaction point	0.04
Horizontal linear tune shift per interaction point	0.04
RF phase angle	156.84°
RF bucket height	4.88×10^{-3}

The lattice parameters and operating characteristics for the part-time dedicated synchrotron radiation mode have been studied preliminarily. The parameters in this mode are shown in Table 2.

Table 2. The main parameters in the part-time dedicated synchrotron radiation mode[2]

Energy	1.1 GeV	2.8 GeV
Circulating current	150	150 ma
Number of bunches	160	160
Number of electrons	7.4×10^{11}	7.4×10^{11}
Horizontal and vertical betatron tune	7.25	7.25
Transverse damping time	141	8.5 ms
RMS bunch length	1.8	4.6 cm
Uncoupled horizontal emittance	3×10^{-2}	0.192 mm.mrad
Touschek life time	23	100 h.
Quantum life time	100	54 h.
Total life time	8	7 h.
Horizontal natural chromaticity	-11.1	-11.1
Vertical natural chromaticity	-13.7	-13.7
Momentum compaction factor	0.023	0.023
Peak RF voltage	0.37	1.07 MV
RF synchronous phase angle	178.1°	150.9°
Radiation loss/turn	124	522 keV
Radiation power	1.7	78 kW
Fundamental mode RF dissipation	7.5	63 kW
Critical wave length	43.4	2.63 A°
Critical energy	0.285	4.71 keV
Factor of merit	0.105	0.105

The main ring magnet system consists of 40 dipoles and 60 quadrupoles, 8 insertion quadrupoles, 4 low field dipoles, 4 sets of wiggler magnets and several kinds of correction magnets. Most kinds of magnets have laminated cores to insure uniformity of magnetic performance.

The main ring dipoles are C type to permit easier access to the vacuum chamber for repairing, installation and utilization of synchrotron radiation. The main ring quadrupole magnets are of full symmetrical four quadrant construction. The main parameters of the magnets are shown in Table 3.

Magnet power supply:

The twelve phases SCR bridge circuit is adopted. The bending magnets are powered in series by one power supply. The quadrupoles are divided into 12 groups and each is powered by separate adjustable power supply. The main winding of insertion quadrupoles are connected in series with the bending magnet

Table 3. Composition of the magnet system of the storage ring

elements	number of elements	magnetic length	max. strength	aperture required	geometr. aperture
Main dipoles	40	1.6	0.9034T	56x97 mm^2	70x120 mm^2
Low field dipoles	4	0.5	0.4500T	38x56 mm^2	70x120 mm^2
Quadrupoles	60	0.4	0.1241T/cm	56x97 mm^2	Ø 110 mm
Insertion quadrupoles Q_1	4	0.6	0.1117T/cm	102x82 mm^2	Ø 160 mm
Insertion quadrupoles Q_2	4	0.6	0.0795T/cm	72x140mm^2	Ø 160 mm
Sextupoles	32	0.2	84 G /cm^2		Ø 120 mm

circuit and their trim windings are powered by two separated power supplies. The sextupoles are divided into 3 groups and powered by separate supply for each group.

The long time current stability of B and Q magnet power supplies are 10^{-4} and the current tracking tolerance between B and Q are 10^{-3}.

Vacuum system:

An average pressure of 1.5×10^{-8} torr in the presence of the designed circulating current is required and at the experimental regions, an even lower pressure 10^{-9} torr is desired. The vacuum chamber is made of Al alloy. Distributed sputter ion pumps and 100 l/s lumped sputter ion pumps are used.

A section of Al vacuum chamber is under test now.

RF system:

According to the available RF power sources in our country, frequency of 200 MHz has been chosen. Two cavities with one cell each are located in the straight section symetrical to the interaction point as shown in Fig. 2. Copper cavity is chosen to minimize the power dissipation. The harmonic number is 160 and the peak RF voltage is 1.33 MV at 2.8 GeV. The beam power is 69 kW at 2.8 GeV for 66 ma beam current and the cavity dissipation is 97 kW. Two 100 kW power stations are needed.

Injection system:

The e^+ and e^- beam are injected into the storage ring near the middle point of the two arcs of the ring. The schematic layout of the injection system is shown in Fig. 5. Air core kickers are selected.

During injection and acceleration the beams must be separated at the crossing point by electrostatic plates located symetrically on either side of the interaction region.

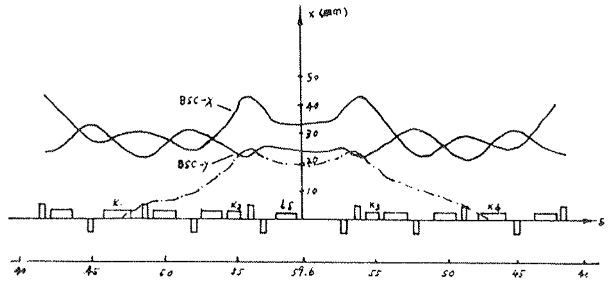

Fig. 5. Layout of Injection System

Instrumentation and control:

We prefer to adopt a two-stage computer controlling system. A main computer and several microprocessors serving as front-end computers would be used for the storage ring and beam transport system.

Beam position monitors, light monitors, scrapers, tune detectors, and feed back strip line will be mounted in the straight sections.

Building:

The cross-section of the tunnel for the storage ring and transport line is 3×4 m^2 and 3×2.5 m^2 respectively. The beam center line of the storage ring is 3 m higher than that of the linac.

References

1. Summary of the Preliminary design of Beijing 2.2/2.8 GeV electron-positron collider (1982).

2. BEPC/TH 83-05.