# BRIEF OVERVIEW OF PARTICLE ACCELERATORS IN CHINA

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*Abstract*

A brief overview of the main particle accelerators in China is given. New projects in the near future are also simply described.

## 1 INTRODUCTION

The Beijing Electron Positron Collider (BEPC), the Heavy Ion Research Facility in Lanzhou (HIRFL) and the Hefei Synchrotron Radiation Facility (HESYRL) constructed in the late 80s have provided very good conditions for the development of China's experimental research of fundamental particle physics, heavy ion nuclear physics and research of synchrotron radiation application. In the last 10 years or so, they have been continuously upgraded. And consequently, their performances have been greatly improved. Based on the general situation of today's China, new plans have been put forward to further develop these three main accelerators since 1996. Meantime, a large new project–the third generation Shanghai Synchrotron Radiation Facility (SSRF) has been proposed.

All the above-mentioned new plans have been approved except for the new plan of BEPC.

As for low energy accelerators, many of them have been converted for directly serving the national economy, only a small part of them remaining for basic research. During the past several years, the linear accelerators for medical radio-therapy, industry radiography, high power electron HV accelerator for industrial irradiation processing and compact cyclotron for short-lived isotope production have got a rapid development. Meanwhile, the AMS technique based on tandem and mini-cyclotron also has made great progress.

## 2 MAJOR ACCELERATOR ON BASIC RESEARCH

The BEPC, HIRFL and HESYRL are the major facilities used for carrying out basic research. The first two were completed in the late of 1980's and the last one was finished in 1992. Their current status and new development plan in the near future are summarized as follows.

### *2.1 BEPC*

The BEPC is operated for both high energy physics and synchrotron radiation experiments. The operation time per year had been about 5500 hours with the operation efficiency of about 95% up to March 1995.

For high energy physics, with the improvement of operation, the integrated luminosity of the BEPC went up year by year from 1992 to 1994. Many important physics results have been obtained, such as the τ-mass measurement, the deeper understanding of ξ(2230) particle and so on.

The machine was shut down from June 1995 to March 1996 for upgrading luminosity. During this period many important improvements have been made.

By using the newly designed and constructed RF power supply, such as the 150 MW modulators and 65 MW klystrons and other improvements on the linac, the output beam energy from the linac was increased from 1.3 GeV to 1.55 GeV in May of 1996, which met full energy injection into the ring for the J/ψ experiment.

The BEPC central computer control system, the linac local control system, the injection local control system and the security protection system have been greatly improved or newly re-constructed. The central control system is to be transformed into a distributed one based on a DECnet to make it faster in response and more reliable in performance. The beam monitor system, including the beam position monitor, tune and the bunch size measurements has been also well improved on both its measurement precision and speed.

Unfortunately, in the beginning of 1997, it was found out that the feedthrough of the new main drift chamber sparkled when the 4 kV high voltage was applied. More than half a year was spent on solving this problem. So the machine has been shutdown again since last June after one and half a month running for dedicated synchrotron radiation experiments and machine study. It is being commissioned in this month.

Finally the insertion quadrupoles were moved about 40 cm towards to the interaction point (IP), and by decreasing the vertical β-function at IP from 8.5 cm to 5 cm , the peak luminosity at J/ψ energy (1.55 GeV/beam) was increased by a factor of 1.5~1.7 and it reached more than $4.0 10^{30}$ $cm^{-2}s^{-1}$ in May of 1996. The hardware of the single interaction point experiment has been prepared well. With this experiment, further increase of the peak luminosity is expected.

For the dedicated SR mode which lasts one to two months per year, the electron beam with an energy of 2.2GeV and a current of 30~80 mA was offered. Since 1991, about 5000 hours of dedicated beam time has been provided to more than 100 users from 35 institutes and universities around the country, and the number of the executed proposals is over 200 in the past five years. Progresses and achievements in various scientific areas have been obtained in most of the research activities at 11 experimental stations.

The new beam lines 3W1A and 3W1B with the multi-period wiggler were constructed and installed. The wiggler made of permanent magnets has 5 periods and a field strength of 1.5 Tesla. The photo flux from the new beam lines raised by an order magnitude (~$10^{14}$ ph/s.rad).

For further development, the high luminosity Beijing Tau-charm Factory(BTCF) was proposed. The peak luminosity of the normal mode is $110^{33}$ $cm^{-2}s^{-1}$ at 2.0 GeV and the possibility to realize the longitudinal polarization mode and monochromatic mode in the future is to be provided. The machine consists of two rings with a symmetric vertical separation, each with a circumference of 385m, micro-β ($\beta_y^*$=1 cm) at interaction point is to be adopted. The total beam current per beam is 560 mA. There are 86 bunches per beam with a small horizontal crossing angle (±2.6mrad). Superconducting quadrupoles in interaction region and single cell superconducting cavities are to be used.

The feasibility study of BTCF has been made in the last two years by the IHEP with collaborators from domestic and foreign research institutions. A lot of problems have been preliminarily discussed in this study, such as the high current, multi-bunch, many topics related to the beam instabilities, superconducting techniques, very low impedance vacuum chamber and so on. Since the BTCF is a largest project for basic research, and large financial support for building this machine is needed, it could hardly be approved in the foreseeable future. Hence, another proposal of using the pretzel scheme in the BEPC ring to raise the luminosity to $10^{32}$ $cm^{-2}s^{-1}$ is being discussed recently. Fortunately, most R & D items of both these two proposals are similar except for the accelerator physics. We hope that the R&D fund for this project will be approved in near future.

### *2.2 HIRFL*

The HIRFL consists of the injection SFC ( a Sector Focus Cyclotron, K=69) and the main accelerator SSC (a Separate Sector Cyclotron, K=450). Now, the HIRFL system can provide a beam time of 3500 h/year for physics experiments, and the ion species are from Carbon to Xenon. Since 1995, some important experimental results have been obtained on HIRFL. For example, the synthesis of six new nuclides ($^{208}$Hg, $^{185}$Hf, $^{237}$Th, $^{175}$Er, $^{239}$Pa, $^{235}$Am) and the decay scheme establishment of four new nuclides ($^{153}$Er, $^{157}$Yb, $^{209}$Fr, $^{130}$Cs).

Two upgrading items have been completed recently. One is the development of a new injector system of SFC. It includes the addition of a new type of ECR, the improvement of the vacuum of SFC and the modification of the vertical injection system of SFC. Then, the ion species can be extended from Xenon to Uranium, and the beam intensity can be increased by ten times. The other is that a new beam-line RIBLL (Radioactive Ion Beam Line in Lanzhou) behind SSC has been built. By strong focusing and double achromatizing, the RIBLL can provide some utilizable beams with short lifetime, perfect quality, high RIB intensity, polarized RIB and isomeric state beam for RIB physics research. RIBLL has been completed last October. Several typical RIBs have been obtained, such as $^{19}$Ne, $^{17}$F and $^{17}$N with intensity around $\geq 10^6$pps.

For further development in the field of radioactive nuclear beam research, a new accelerator complex CSR, has been planned in HIRFL. It is a multi-purpose Cooler-Storage Ring system which consists of a main ring (CSRm) and an experimental ring (CSRe) with a circumference of 161m, 94m respectively. The maximum magnetic rigidities of the two rings are 10.6 T.m. and 6.4 T.m. respectively. The two existing cyclotrons SFC (K=69) and SSC (K=450) of HIRFL will be used as its injection system. The heavy ion beams with an energy of 10~100 MeV/u from HIRFL will be accumulated, cooled and accelerated to a higher energy of 100~400 MeV/u in the main ring, and then extracted to produce radioactive ion beams (RIB) or highly charged state heavy ions. After that, the second beams (RIB or highly charged state ions) can be accepted by the experimental ring for internal target experiments.

The CSR system will be used for those studies of RIB physics, atomic physics with high charged state heavy ions and nuclear astrophysics. It will be approved by our government in 1998. The construction period is five-year. Fig.1 gives the overall layout of HIRFL-CSR.

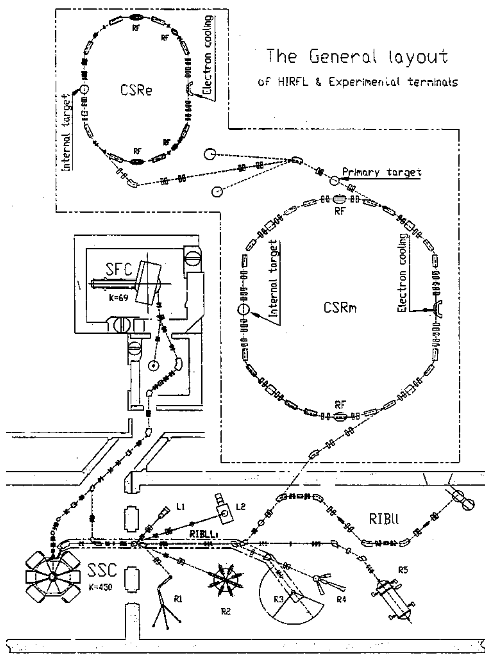


Fig. 1 Layout of HIRFL-CSR

### *2.3 HESYRL*

The HESYRL consists of mainly of a 200 MeV linac and an 800 MeV storage ring. It has been running for 25000 hours for SR users since 1993. The routine typical operation parameters are: beam current 150 mA at 800 MeV, beam emittance ~166 nm.rad and the lifetime of 10 hrs.

So far the HESYRL has had five beamlines and relevant experimental stations in the VUV and soft X-ray region for users, i.e. X-ray lithography, time resolved spectroscopy, photochemistry, soft X-ray microscopy and photoelectron spectroscopy beamlines and experimental stations. About 100 user groups from different institutions were registered and 120 research items were selected this year. Some important results have been obtained.

In order to meet further requirement of the users, a new upgrading plan of the HESYRL for the next five years has been approved. It contains:

- Improvement of the performance of light source

In order to further lower the emittance from 160 nm.rad to 27 nm.rad at 150 mA, i.e. to operate the storage ring with high brightness mode (HBLS), a new four ferrite kicker system will replace the old three air core single turn kicker system at injection. To upgrade the beam intensity, a new RF cavity will be developed. Meantime the RF system and current stability of the power supply will be improved. A new feedback system will be added to make the beam spots at the experiment station more stable, ie. less than ±50 μm. A new 2.668 m long, 29 period permanent magnet undulator will be developed in order to increase the brightness to ~$10^{16}$ Ph./(s.mm$^2$.mrad$^2$.0.1 bandwidth) with the HBLS mode.

- Construction of beamline and experimental stations

Eight new beamlines and experimental stations will be built. Such as surface physics, X-ray diffraction and scattering, LIGA and atomic and molecular station, etc.

### *2.4 SSRF*

In order to meet the requirement of the development of science and technology of China in the 21st century, especially in Shanghai region, a new project, SSRF, has been proposed since the end of 1994.

The general layout of the SSRF is given in Fig. 2.

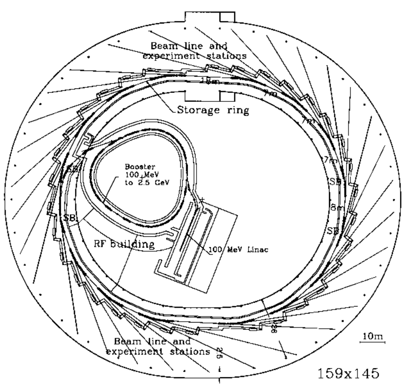


Fig. 2 General Layout of SSRF

The energy of the SSRF is 2.2 GeV ~ 2.5 GeV due to budget limitation. So it will be a VUV and soft X-ray light source. Due to lower natural emittance (~4 nm.rad), the SSRF will provide a high brilliance of VUV light (≥$10^{18}$ Ph./s.mm$^2$.mrad$^2$.0.1%BW, 10 eV, undulator), soft X-ray (≥$10^{19}$ Ph./s.mm$^2$.mrad$^2$.0.1%BW, 3 keV, undulator) and hard X-ray (≥$10^{15}$ Ph. /s.mm$^2$.mrad$^2$.0.1%BW, 3~60 keV, superconduction magnets).

With two 18 m long straight sections in the lattice, the SSRF has the growth potential for future development.

The design goal of the SSRF based on an extensive investigation of the future users and potential users of the SSRF, the 15 beam lines and experimental stations of the SSRF were proposed, such as protein crystallography, XAFS, general purpose diffraction, photoelectron spectroscopy, general purpose scattering, soft X-ray microscopy, LIGA, etc.

However, it is due to budget limitation that only 5 to 7 beamlines of them (including 2~3 insertion devices) will be constructed during the initial stage.

The total cost of the SSRF is no less than 800 million Chinese Yuan (in the FY 1995 Yuan). We hope the SSRF will be completed near the middle of 2003. After long-term discussion, the R&D funds (about 80 million yuan) has just been approved.

## 3 LOW ENERGY ACCELERATORS

In the past decade, low energy accelerators, especially those aiming at applications of radiotherapy, radiation processing, radiography, etc. have got very rapid development. Here only some of the latest progress will be briefed.

### *3.1 Linear accelerator*

So far the medical electron linear accelerators have played an important role in the treatment of human cancers. It has been estimated that there are approximately 1.6 million new cancer patients and 1.3 million deaths annually in China. So recently the medical linac has undergone a rather rapid development under the stimulation by strong requirement from huge cancer patients in China. The number of medical linacs totals up to 300. However, it is still not enough to satisfy the need of the whole country. About half of these medical linacs in Chinese hospitals are home-made, most advanced radiation therapy equipment is imported. The energy of most home-made linac is around 4-6MeV. A 14 MeV standing-wave medical electron linac has been developed recently, which can provide two modes X-rays, 6 MV and 15 MV, and five mode E-rays, 6,8,10,12,14MeV. The dose rates of the machine are 2.5 Gy/min.m for X-ray mode and 4.0 Gy/min.m for E-ray mode respectively, the radiation field size is 40cm40cm.

Electron accelerators used for nondestructive inspection of metals and nonmetals are also produced in China. Only a few of electron accelerators used for radiography are made in China.

Recently, Tsinghua university(TSHU) is successful to use the linac for the application of large container on-line inspection system at customs. The maximum dose rate of this machine reaches 40 Gy/min.m, the beam spot size is less than ϕ1.5 mm. So it meets the needs of the overall image on the computer screen reflecting the inside of the container. The linac and the inspection system were developed by TSHU.

Another more powerful 9-MeV SW electron linac for radiography had been developed in China. The machine emits a very strong X-ray, and its dose rate exceeds 30 Gy/min.m with a small beam focus spot, ϕ1.5 mm. This linac uses a s-band 2.6 MW tunable magnetron as its microwave power source. The accelerated beam current can reach 120 mA.

Apart from the above application, several linacs have been used for FEL study in recent years. The 30 MeV RF linac of the IHEP was adopted to construct a compton regime IRFEL, which achieved the saturation lasing in 1993, the output pulse average power was 2~5 kW. A microwave electron gun was used as the high brightness injector. The high current 3.5 MeV induction linac of Chinese Academy Engineering Physics (CAEP) was used to develop a millimeter wave FEL amplifier facility. In 1994, the output peak power exceeded 140 MW. A 4 MeV high brightness ($3\times10^9$/m$^2$.rad$^2$)L-band linac has been constructed to acquire the FEL with 100~200 μm at Chinese Institute of Atomic Energy (CIAE). Moreover, a wide band FEL user facility in Shanghai (SFEL) based on a 50 MeV RF linac is under construction.

### *3.2 Proton Linac and Heavy Ion RFQ*

In recent years, the 35 MeV Beijing Proton Linac (BPL) has mainly been dedicated to medical application with interesting results obtained. The neutron beams are produced by the 35 MeV protons bombarding the beryllium target and are used for curing cancer patients. So far, more than 300 patients have been treated by the fast neutron.

Due to the extensive progress of the accelerator science and technology, it is possible to build a high intensity medium energy proton accelerator for many very important applications, especially for the nuclear waste transmutation and nuclear energy amplifier. A proposal for developing the Accelerator Driven Nuclear Power System(AD NPS) is being submitted by the IHEP and CIAE. As the first step, a verification device is suggested to be build in next ten years, it consists of a 150 MeV with average current 3mA proton linac and a zero-power subcritical blanket. The main purpose of building this Linac is not only to meet the requirement of principle verification but also to be a prototype of future full scale linac. It will be used to understand the problems and difficulties in the design, construction, and high CW operation etc. As the second step, a demonstration testing device will be build in another ten years, it mainly consists of a 1GeV, 10-20mA proton linac and corresponding sub-critical reactor and target system.

As for the research of heavy ion RFQ, Peking University (PKU) has built the prototype of 26 MHz Integral Split Ring (ISR) RFQ. Since 1994, the beam test has been carried out. The length of the tank is 0.9 m and its diameter is 0.5 m. At RF peak power of 40 kW with a duty factor of 1/6, the designed inter-rod voltage of 75 kV is achieved. Nitrogen ions with average output beam current is 16 μA, the transmission efficiency from 22 keV to 300 keV is 50%. On the bases of the prototype, a 26 MHz ISR RFQ for 1 MeV Oxygen ions is being constructed for the studies of heavy ion RFQ and ion implantations.

### *3.3 Cyclotron*

There are four compact cyclotrons with the energy around 30MeV and beam current 300 μA for medical radioactive isotope production, and one for the Shanghai Institute of Nuclear Research (SINR) supersensitive mini-cyclotron mass spectrometer (SMCAMS).

The first compact medical cyclotron was imported from U.S. in 1984. The second one was imported from Belgium in 1993, and was completed at the end of 1995. The third one was put into operation in 1995 at CIAE. It is a fixed-field and fixed frequency isochronous cyclotron accelerating $H^-$ ions beam up to 30 MeV with the extracted beam intensity of more than 350 μA. Its power consumption is less than 100 kW and it was originally designed by IBA, Belgium. Some major modifications of the design have been made. All equipment, such as RF, power supplies, vacuum and water cooling system, except ion source and strippers were made in China. The performance during last year was excellent. Seven medical short-lived neutron isotopes have been produced for the home market. The fourth one was presented by UCLA,USA. It is being installed. The SMCAMS is dedicated for $^{14}C^-$ analysis for dating. The commissioning was carried out in the middle of 1993. Primary measurement showed that the high resolution about 3000 and abundance sensitivity of $10^{-15}$ have been approached. This shows that a series of new ideas and technical measures adopted in SMCAMS are feasible and correct. In order to upgrade transmission and $^{14}C^-$ counting efficiency and to carry out alternate acceleration of different particles: $^{12}C^-$, $^{13}C^-$ and $^{14}C^-$ further improvement is being carried on.

### *3.4 High Voltage Electron Accelerator*

#### *3.4.1 Tandem accelerator*

Since the first 21.0 MV tandem accelerator was put into operation in TSHU in 1981, 15 tandem accelerators have been set up in succession in China.

The HI-13 tandem accelerator of CIAE is a HVEC type machine with inclined field and large aperture accelerator tube, Laddertron charge system and horizontal tank. It was accepted in 1986 and put into routine operation in 1987. Since then, the operation status of HI-

13 tandem machine has performed very well.

Some main spare parts, such as the Laddertron chain, the high voltage divider resisters and the vacuum components, were completed by the domestic production with much better performance than that from HVEC. By the end of 1995, more than 137 programs of nuclear physics studies have been conducted with experiments.

The EN-tandem accelerator from Oxford was reconstructed and put into operation in early 1990 at PKU, which can provide about 1000 hours for experiments each year. The accelerator mass spectroscopy (AMS) is the main field of research and application for this machine. A variety of ions from Be to Br have been accelerated successfully for various purposes. The high intensity multi-target Cs sputter ion source, fast alternating injection system, beam transport and analyzing elements, particle detection and data acquisition system are adopted. For whole machine, the measurement precision of AMS can reach to 1.7%. The efficiency of the whole AMS beam line lies in the range of 25 ~ 40%. And the sensitivity for this facility can achieve about $3 \times 10^{-14}$ for measurement and $1.0 \times 10^{-15}$ for limitation sensitivity. More than 600 samples have been measured since 1993. For studying the dating of Xia-Shang-Zhou dynasty, further improvement aiming at higher precision (about 0.1~1.0%), sensitivity (about $10^{-15}$) and efficiency (>50%) are going to be proceed.

The $2 \times 6$ MV tandem accelerator at SINR is the highest terminal voltage tandem machine made in China, which was designed and constructed by SINR itself. This machine was put into operation in 1992. Since 1992, this machine has mainly been used for AMS researches and applications and low energy nuclear physics experiment studies. Because of the budge limitation, the operation time is limited to two days each weak only.

For some other small tandem accelerators, such as the $2 \times 3$ MV tandem in Shanghai Fudan University, $2 \times 2$ MV tandem in Lanzhou Institute of Modern Physics, etc., the main field of researches and applications are the ion beam analysis and ion implantation and so on.

### *3.4.2 Electron Accelerators for radiation processing*

The industry of radiation processing in China is rapidly increasing. The total number of electron accelerators for radiation processing are about 45 and the total electron beam power is 1.5 MW at present. The main applications of radiation processing is radiation crosslinking of wire and cable, heat shrinkable film tube and foam, food irradiation, etc.. The most popular distributed type in China is the Dynamitron. In the past four years, besides the Xian-Feng Electric Generator Factory (2 MeV), the IHEP and SINR have completed the dynamitron with 3 MeV and 20 mA for cable irradiation.

### *3.4.3 Intense Relativistic Electron Beam Accelerator*

The Intense Relativistic Electron Beam Accelerator (IREB) technology has been rapidly developed since the 1960's. At present, more than 25 sets of IREB accelerator have been installed and operated. Among them, the Flash I (8MeV,100kA, 80ns)and linear induction accelerator (10.3 MeV, 2.1 kA, 70 ns) at CAEP, the Flash (1MV, 1MA, 70ns) at Northwest Institute of Nuclear Technique (NINT) are the major facilities. In recent years, NINT has devoted to development of the induction energy storage and high repetitive pulsed electron beam accelerator. Relative technologies and components are being studied.

In the early 1970's, IREB machines were mainly used for flash X-ray, radiography, radiation simulative source and used for studies high velocity motion process transient radiation electronics effect and thermo-machanical effect of material and structure. Recently, some of them, such as the linear induction accelerator of CAEP, have been used as high brightness electron source to develop FEL, some for developing the technology of high power microwave and for pumping excimer laser.

## 4 Conclusion

With the development of our national economy, there will be an increased demand of accelerators for industrial and medical use. Low energy accelerators for application will enjoy a rapid development not only in terms of quantity but also in terms of variety and quality in next 5 years. Meanwhile, large facilities for basic research will be greatly improved and upgraded and new large installation matching our economic strength will also be developed correspondingly.

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