COMMISSIONING OF HIRFL

WEI BAO-WEN

Institute of Modern Physics,Academia Sinica
P.O.Box 31,Lanzhou,PRC

ABSTRACT

After a short recall of the HIRFL scheme, the magnetic field mapping,vacuum pumping and rf conditioning of the main accelerator SSC are discussed. The results of beam tuning for HIRFL are also discussed.

HIRFL SCHEME

The HIRFL scheme and parameters have been described in previous publication[1]. It consists of following main parts:

- an injector SFC with energy constant K=69,
- a main accelerator SSC with energy constant K=450,
- 60m beam line fron SFC to SSC,
- experimental areas and concerning beam lines.

Table 1 gives the beam properties of HIRFL. A photograph (figure 1) shows the main accelerator SSC of HIRFL.

Table 1: Beam properties of HIRFL

		^{12}C	^{40}Ar	^{132}Xe
SFC	Z	4	10	11
	E(MeV/u)	7.6	4.2	0.5
	$\Delta E/E$	$2\ 10^{-3}$		
	ε(mm.mrad)	12		
SSC	Z	6	16	23
	E(MeV/u)	88	46	5
	$\Delta E/E$	$2\ 10^{-3}$		
	ε(mm.mrad)	4		

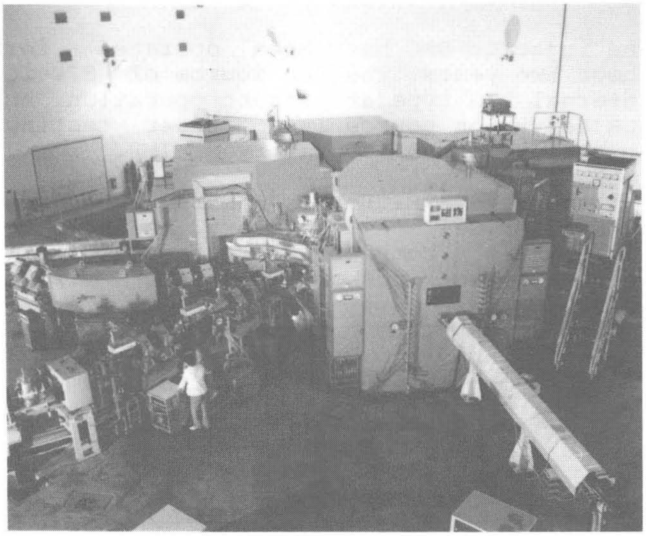

Fig.1: A photograph showing the main accelerator SSC of HIRFL.

The beam diagnostic system of HIRFL consisting of diagnostic elements such as Frardy cups,slits,secondary emission multiwire chambers,centre phase probes,radial differential probes and position probes and measuring units such as beam energy measurements and emittance measurements play an active role in the beam tuning and beam optimization.

The control system of HIRFL is based on CAMAC distributed intelligent control. The local control stations are designed according to HIRFL's subsystems such as injector,beam line,injection and extraction,magnet,vacuum, rf, diagnosis and measuring units. They are linked by CAMAC serial dataway and drived by master computer thro CAMAC auxiliary crate controller then to realize CAMAC communication. In these stations,all the power supplies are controlled by microprocessors and the positioning devices are controlled by stepping motors or pneumatic units.

Two VAX-8350 computers, each having 12 MB memories and sharing 4x520 MB disk group and 2x300 MB removable disk mass storage cluster, with comfortable peripheral equipment are installed in the central control room of HIRFL. One of them is used as a master comupter for HIRFL control system. Another one is used as a reserve computer when the former one is in fault. Additional, it is also used for calculations and off-line data processing for the experiments carried out in the experimental areas.

The main console in the central control room consists of storage oscilloscope, signal observation and seven touch panels.

INJECTOR SFC

The injector SFC has been operated for about two years. The ion source of SFC is internal PIG type at present operation. An ECR heavy ion source is now under testing in the cyclotron laboratory of IMP.

The source, CAPRICE, is introduced from FRANCE, Mr.Gelle's laboratory. As shown in Fig.2, it is a compact two stage source. There are two kinds of magnetic mirror fields: radial and axial. It gives a minimum magnetic confinement. The raidal confinement field is formed by a hexapole of $SmCo_5$ with 4kG on the poles. The axial field is created by four solenoids with rather low electrical power consumption of 35kW for having a completely enclosed return iron yoke.

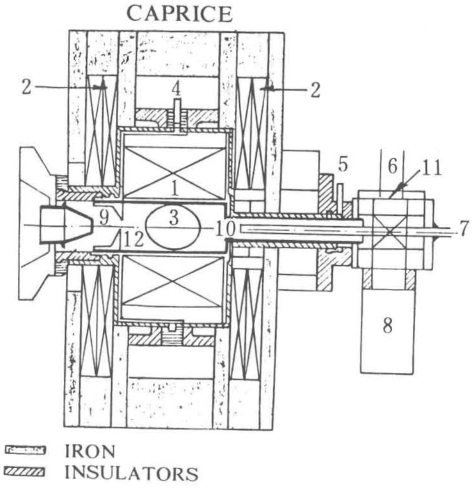

Fig.2: Caprice source: (1) magnets. (2) solenoid coils. (3) closed ECR surface. (4) water cooling inlet. (5) water cooling outlet. (6) rf power inlet. (7) gas inlet. (8) turbo mplecular pump. (9) ions extraction. (10) gas inlet tube. (11) rf window (12) removable vacuum chamber.

A turbmolecular pump of 50 ℓ/s is arranged in the first stage. The microwave power, 10 GHZ and 500 W_{max} in CW regime, is also injected from here through a tight BeO window. The plasma cavity and the hexapole of the source is isolated up to 30kV maximum. The working and mixing gas consumption are controlled independently by two valves respectively. In the first stage with vacuum of about 10^{-3} torr, a cold plasma is iginited by ECR and then diffuses towards the second stage which is at even low presure. After suffering a further ionization inside the enclosed ECR surface, the ions are extracted through a hole of ϕ6 on a plasma electrode. When the source works for producing metallic ions, a metal sample with an appropriate diameter is used. The tip of the sample is positioned to approach more or less the confinement surface in the second stage.

The ion yields of this source are shown in Fig.3 and 4 for gaseous and metallic ions respectively.

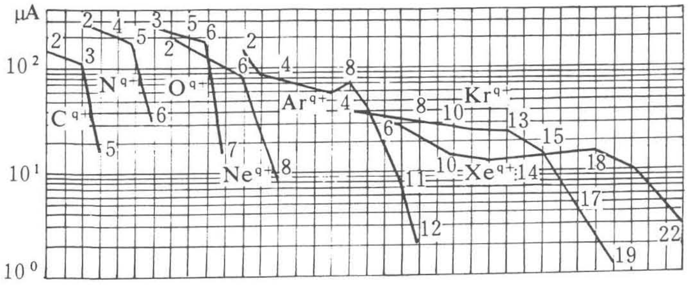

Fig.3: Gaseous ion yields of the ECR source, ϕ6, 15 KV.

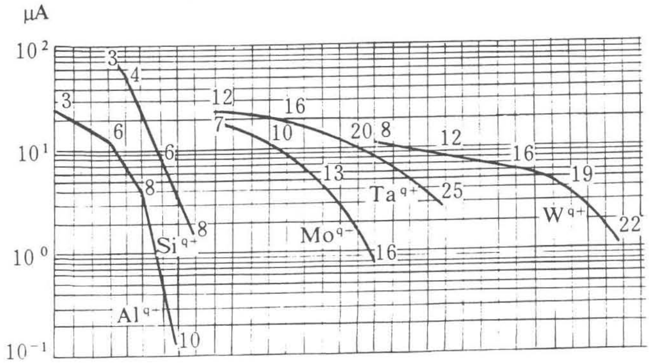

Fig.4: Metallic ion yields of the ECR source, ϕ6, 15 KV.

As we can see, it is especially suitable for getting high charged ions with low working material consumption. The other performances, such as the stability of the extracted beam, the reliability and the reproducibilty are good. There is no corroded parts inside the source, so that it can work for weeks without any interruption.

This source will be used as an external ion source for SFC. The injection system is now under designing. By using the ECR source, the acceleration of ions can be expanded from Xe to Ta, and maximum energy for light heavy ions can be reached up to 125 MeV/u.

THE BEAM LINE FROM SFC TO SSC

The beam line from SFC to SSC consists of 6 D-magnets,34 Q-magnets,24 steering magnets,a stripper and two bunchers. The magnetic field of D-magnets is between 10-12 kG,and the homogeneity is better than 0.1% within ±15cm around the centre trajectory in the radial direction. The gradient of Q-magnets is between 0.8-1.2 kG/cm,and the non-linearity is less than 1% within 0.7 diameter of the aperture. The magnetic field of the steering magnets is between 300-400 G,and the homogeneity is about 2%.

The stripper is performed by carbon foil. The thickness of the foil is about 65 µg/cm². The average lifetime of the foil is about 60-70 hrs under the bombardment of several µa C^{4+} beam. A frame holding 60 pieces of foils is arranged at the stripping position,so that,the foil can be easily renewed under the vacuum condition. A DC voltage is slao applied to compensate the energy loss when the beam goes through the stripper.

A mono-structure buncher has been designed. The power tube of the rf amplifier is riden on the cavity directly. The gap between the anode of the power tube and the drift tube of the cavity is composed as a capacitor to couple the cavity with the rf amplifier. This capacitor can be adjusted under the vacuum condition for changing the parameters of the rf amplifier. The distance of the drift tube and the DC power supply of the power stage can be also adjusted to the required value for adopting the harmonic number and matching purpose through the whole working band. A new super-vaportron power tube was trially produced with the existing water cooling system. The testing results are given in table 2.

Table 2: Testing results of the buncher

Frequency range	25-56MHZ
load resistance	500-1300
Rf voltage (37.572MHZ)	40kV(peak)
Dynamic Q value (37.572MHZ)	5500
Amplitude stability (open loop)	$2x10^{-2}$

The preliminary results of the beam line tuning show that the transmission efficiency from the exit of SFC to the entrance of SSC for C^{4+} beam (C^{6+} after stripping) is about 50%.

MAIN ACCELERATOR SSC

Isochronous Magnetis Field Setting of SSC

For a given particle with charge states Z, mass number A and momentum P moved in the (r. θ) plane under a homogeneous magnetic field in the Z-direction, the equilibrium closed orbit E.O. can be calculated by resolving the following equations in (r.θ.Z) coordinate system:

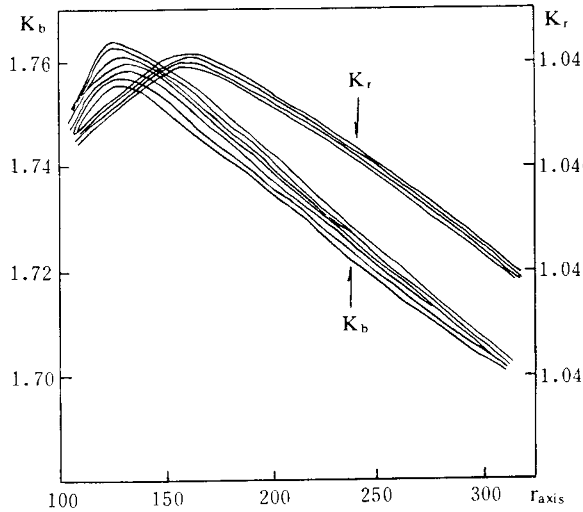

Fig.5: K_b and K_r values for seven reference levels of 6,10,12, 14,15,16 and 17kG for remaining perturbation magnetic field.

$$\frac{dr}{d\theta} = \frac{r\,P_r}{\sqrt{1-P_r^2}}$$

$$\frac{dP_r}{d\theta} = \sqrt{1-P_r^2} - \frac{ZerB(r.\theta)}{P}$$

$$\frac{ds}{d\theta} = \frac{r}{\sqrt{1-P_r^2}}$$

where S = distance
$P_r = V_r/V$
$P = A\,m_0 v$
e = electron charge
m_0 = mass unit
$B(r.\theta)$ = magnetic field map

Then corresponding to radial coordinate r_{axis} of the orbit E.O. and the magnetic field $B_{axis}(r_{axis})$ along the sector hill,we define

$$K_r = \frac{r}{\bar{r}}\ , \qquad K_b = \frac{B(r)}{\bar{B}}$$

where $\bar{r} = \int_{EO} r\,ds / \int_{EO} ds$

$$\bar{B} = \int_{EO} B\,ds / \int_{EO} ds$$

Fig.5 gives the K_b and K_r values for seven reference levels of the magnetic field.The isochronous magnetic field law B_{iso} along the sector hill is given by

$$B_{iso}(r_{axis}) = \frac{A}{Z}\,\frac{m_0c^2}{ce}\,\frac{1}{r_{axis}}\,\beta\gamma K_b K_r$$

where c=light speed, m_0c^2=931 MeV

$$\beta = (2\ f_{rev})\bar{r}/c, \qquad \gamma = 1/\sqrt{1-\beta^2}$$

$$f_{rev} = \frac{c\sqrt{\left(\frac{E_{ex}}{m_0c^2}\right)^2 + 2\frac{E_{ex}}{m_0c^2}}}{2\pi r_{ex}\left(1 + \frac{E_{ex}}{m_0c^2}\right)}$$

E_{ex}=extraction energy
$\bar{r}_{ex}$=average extraction radius

The isochronous magnetic field setting can be realized through the following procedure[2]:

1. For given accelerated ion with A, Z and f_{rev}, the required isochronous magnetic field law $B_{iso}(r_{axis})$ is calculated.
2. B_{axis}, K_b, K_r and a_{ij} are deduced referring to $B_{iso}(r_{axis}=2.52m)$ by using linear interpolation method.

$$a_{ij} = \partial B_i/\partial I_j$$

3. The required trim coil contribution ΔB is obtained:

$$\Delta B = B_{iso}(r_{axis}) - B_{axis}(r_{axis})$$

4. The iterative least square method is used for getting the required trim current I_j, j=1,2,...25

$$Q=\sum_{i=1}^{N}\left(\sum_{j=1}^{M} a_{ij}I_j - B_i\right)^2$$

where N= number of the optimizing points
M= 25,number of trim currents

Comparing the experimental isochronous magnetic field B_{exp} with required isochronous magnetic field law B_{iso}, the deviation δB is in between of 0.05%-0.15%.

$$\delta B = B_{exp} - B_{iso}$$

Vacuum Pumping of SSC[3]

The pumping arrangement of SSC consists of a main pumping system,an auxiliary pumping system,a rough pumping system as well as a liquid nitrogen supply and a venting system. The main pumping system consists of eight modified RKP800 cryopumps from Balzers,each has pumping speed of about $20m^3\ s^{-1}$ for hydrogen and nitrogen. The auxiliary pumping system consisting of two turbo-molecular pumps of the type Pfeiffer TPH 5000 provides a pumping speed of $4.3m^3\ s^{-1}$ for nitrogen. The rough pumping system consists of two ZJZ 600 roots blowers combined with two H 150 mechanical pumps.

After one hr of rough pumping, the pressure in the system can be reduced to 10pa. Then the two turbo-molecular pumps are started. After 100 hr pumping, a pressure of $8x10^{-6}$ pa could be obtained thus satisfying the design requirement.

Rf Conditioning of SSC

Before pusing the cavity into vacuum chamber, we baked the cavity with a continuous rf power. The voltage limitation is about 10kV(peak)/cm under atmosphere.At the same time the outflowing hot water of the hypervaportron TH537 was circulated in the cooling tube every where in the cavity.The whole cavity may warm up to about 70°C, so that the residual organic solvent could be volatilized. Then the rf conditioning can be started in the vacuum chamber under a pressure of about 10^{-5} pa:

1. Passing through the multipactor region
We adopted a continuous 10 kV-peak voltage and tuned the cavity, made good matching between resonator and amplifier at all time.

2. Eliminating the burrs
In order to eliminate the burrs and dirts caused by rf sparking, the high amplitude but narrow pulses were adopted. The duty factor is 1/10 to 1/2.

3. Making outgas by continual high amplitude with high rf power output.

We increased the voltage gradually by a factor of 15% at the beginning and reduced the factor to 2% when the dee voltage approaches the definitive value. Passing through these three stages, the designed voltage,for example, 105 kV at 8.64MHZ was finally obtained.

Beam Tuning of SSC

The extracted beam intensity from SFC is about 1 μa. The transimission efficiency from the exit of SFC to the entrance of SSC for C^{4+} (C^{6+} after stripping) is about 50%. That means that about 750 nA of C^{6+} beam could be reached to the entrance of SSC. The C^{6+} beam was injected into the main accelerator SSC in June of 1988. The injection efficiency of SSC is about 70%.Finally,we extracted the 50 MeV/u C^{6+} beam from SSC on Dec.12 of 1988. The extracted beam intensity from SSC recently is about 30nA.

References

[1] B.W.Wei, HIRFL separated sector cyclotron progress,Eleventh international conference on cyclotrons and their applications. 1986, Tokyo. P176.
[2] M.Barre etc. Proceedings of 9th international conference on cyclotrons and their applications. 1982, P371.
[3] Zhang Shuxiu Vacuum, 38(1988)125.