UPGRADING THE SFC

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ABSTRACT

The ECR ion source,the beam line from ECR to SFC and the electrostatic inflector have been designed and installed to increase the ion species and the beam intensity.The working points are mainly located in the third harmonic accelerating region.The central region was studied carefully and the Dee, dummy Dee were rebuilt to match the external injection system.Other improvements were made to improve the the SFC performance and the operation efficiency.The commissioning of the upgraded SFC is also described.

1. INTRODUCTION

The injector of HIRFL is a 1.7m sector focusing cyclotron (SFC k=69) converted from a 1.5m classical cyclotron.In May 1987 the C^{4+} and O^{5+} beams were extracted from SFC using the internal PIG ion source. To increase the beam intensity and the ion species and improve the beam performances, an ECR external ion injection system was constructed and put into operation this year. Some other improvements were also finished to match the external injection system and to improve operation efficiency. The design, test and commissining of SFC are presented.

2. ECR ION SOURCE AND BEAM LINE

The ECR ion source named Caprice purchased from CENG Lab, and the beam line from the ECR ion source to the SFC have been installed. To meet the need for ions of heavier elements, some possible modifications at the first stage of the ECR ion source had been tried. As shown in Fig.1, component 15, a conical iron ring plays an important role in the formation of the first mirror peak. The position of the ring can be adjusted along the axis to meet the optimum for each ion species. But this movement can only change the position of the mirror peak not its shape. When we cut the ring shorter and made the cone sharper, the shape of the peak become narrow (Fig.2.). As a result, the distance between the two stages becomes smaller[1].

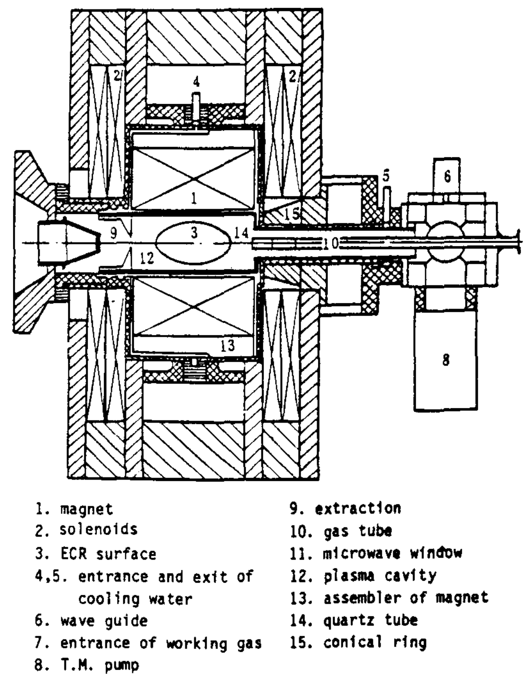

Fig.1. ECR ion source,Caprice.

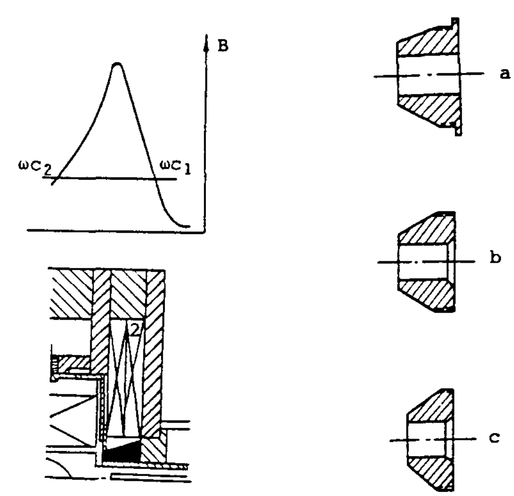

Fig.2. Conical iron ring and the axial field distribution.

It facilitates the plasma diffusion from the first stage to the second one. Figure 3 shows the ion-spectra optimized for Ar^{8+} with He as a mixing gas. It is worth notice that the benefit is based mainly on the improvement of charge state distribution in the plasma at the second stage. This probably implies that by shortening the distance between the two stages the second stage can obtain more preliminary ionized plasma than the neutral working gas from the first stage. In table 1 the results with the new ring are given. For comparision, the results obtained with the original ring are also specified on the left top of each figure. It is very clear that a considerable increase in ion current with a factor of about 1.5 to 2 is gotten for Ne and Ar respectively.

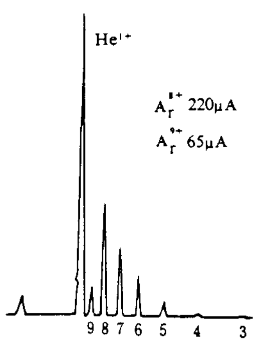

Fig.3. Ar^{8+} ion - spectrum with He as amixing gas.

Table 1. Beam current with the modificated ring

	O	Ne	Ar	Xe
3	315/390			
4		124/300		
5	220/220			
6	206/205	100/155		
7		25.4/35	108/183	
8			110/220	
9			56/105	
11			8.2/15	
15				22/25

The beam is injected from the bottom of the cyclotron SFC. The limited space of the basement brought a lot of trouble to the design and installation of the beam line from ECR to the SFC which is shown in Fig.4. The beam line was designed by using the TRANSPORT code. Only magnetic elements have been used. Two Glasser type lenses focus the beam to the vertical 90° achromatic deflection section, which consists of two 45° dipoles and triple quatrupoles. This section also provides charge state selection with resolution $Q/\triangle Q = 20$. The four quatrupoles EQ06–EQ09 are placed subsequently used to match the phase spaces. The ES01–ES04 are used to match the injection beam to the SFC acceptance. A sprial inflector was adopted to bend and place the beam on orbit .

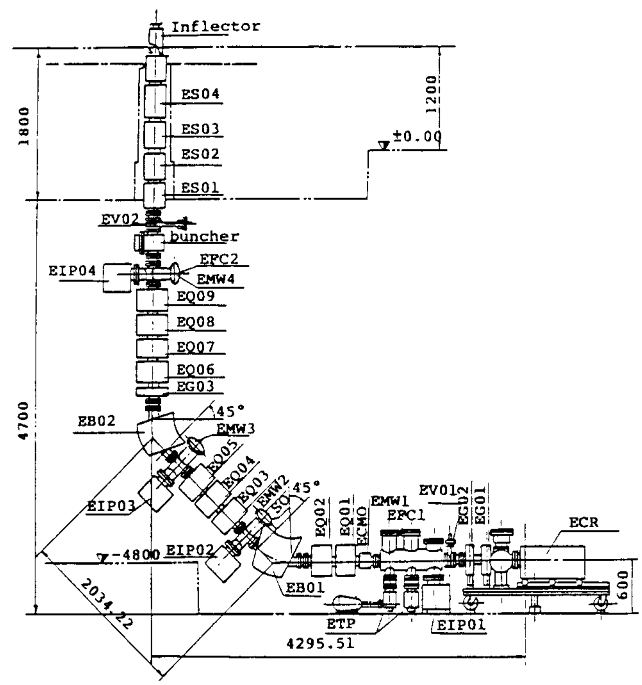

Fig.4 Beam line from ECR ion source to the inflector.

At the entrance of yoke hole a buncher is placed for bunching of the DC beams from ECR ion source. The buncher consists of two parallel mesh plates forming a single accelerating gap, and it is excited by an RF power supply with sawtooth shape voltage. The sawtooth-like waveform voltage is obtained directly from the sine waves by using a waveform converter, not from the combining RF sine waves with fundamental, second and third hamonic frequencies[2).

3. DESIGN OF THE CENTRAL REGION AND THE INFLECTOR

The main parameters of SFC are given in table 2. According to our condition we used CO to calculate the center region of SFC, and used CENTOM and CENTER, writen by GANIL and RCNP respectively, to check the calculated data. Figure 5 shows the opration diagram of SFC for particles with diffirent charge to mass ratios. Because the extraction voltage is limited by the isolation cover of ECR ion source, the voltage value is lower than 20 KV. So we chose the typical particle at point A to design our injection system.

Table 2. Main parameters of SFC

number of sector	3
spiral angle	33°
pole diameter	170 cm
extraction radius	75 cm
mean magnet field	1.6 T
circular coil	12 pairs
valley coil	4 × 3 pairs
dee number	1
dee angle	180°
frequency range	6 - 18 MHz
peak voltage	100 KV
RF power	200 KW
vacuum	5×10^{-5} Pa

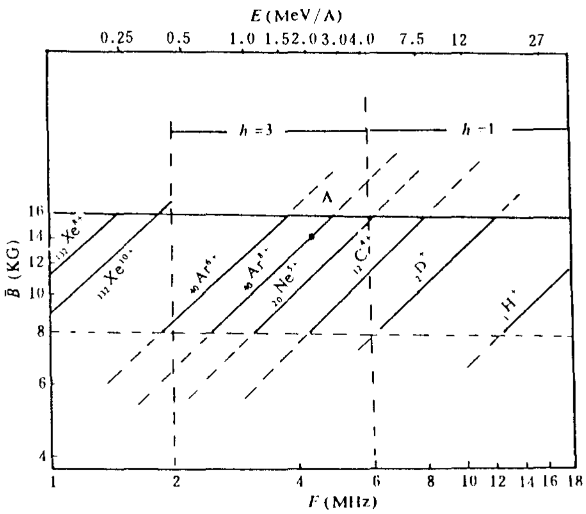

Fig.5 Operation diagram of SFC

To meet the requirement of the installation and adjustment of the inflector, and to calculate the ion trajectories, the electric field was calculated by numerical methods (3D code) and an electrolytic tank was used to measure the electric potential to check the calculated data. The design of the center region is shown in Fig.6.

The inflector is one of the key devices in the axial injection scheme. A spiral electrostatic inflector has been adopted to bend the beam direction by 90° and bring the ion trajectories onto the median plane. Following the used generally design principles and the equations of motion for the central trajectories an unslanted inflector had been designed and fabricated[3]. Its main parameters are listed in table 3.

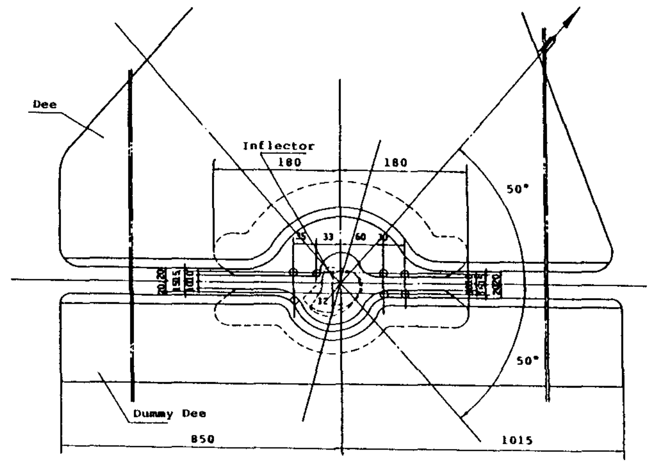

Fig.6 Design of the center region of SFC.

Table 3. Main parameters of the inflector

ECR extraction voltage (max.)	20 KV
Electric radius	
(height of the inflector)	6 cm
Magnetic radius	2.5 cm
k	1.2
β	0
Distance between electrodes	0.8 cm
Side width of the electrodes	2.0 cm
Dee voltage	60 KV
Injection radius	4.5 cm

4. STUDY OF CENTRAL TRAJECTORIES

The equation of the charged particle motion in the certral region had been integrated analytically and the satisfactory results was obtained by using SCDD method. Firstly the displacement of the centres of rotation during the acceleration at third harmonic was obtained and the acceleration can be centred of the machine in several minimeters. Secondly the phase drift caused by the accelerated particles across the gap between Dee and dummy Dee can be controlled into ±5°. To give as large as possible space available for the center region and to improve the vertical electric focusing, the large gain in energy passage through a narrow gap at the first time was chosen. To select an optimum initial phase and to match the optic requirement of the inflector, a pump magnet field introduced by the plug at the region of 10cm has been adopted. The dependence of trajectories in the central region on the injection phase is shown in Fig.7.

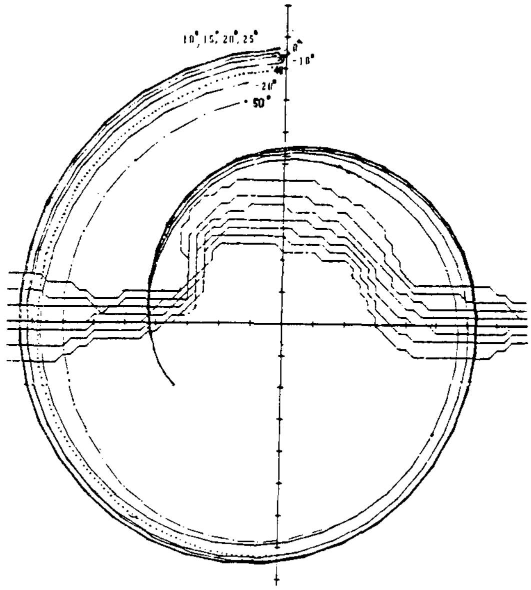

Fig.7 Dependence of trajectories on the injection phase.

Meanwhile to study the beam behaviour in the cyclotron in detail, acceleration simulation was done. Figure 8 shows the acceptance of SFC centre region.

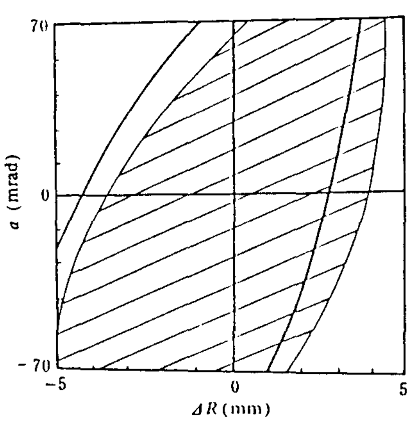

Fig.8 Acceptance of SFC center region.

5. MAGNET FIELD MAPPING AND OTHER IMPROVEMENTS

Because the new main coils took the place of the original one which was used for about 30 years and the external injection system has been adopted , the magnet field must be mapped again. The measurement was performed in case that the vacuume chamber had been installed. All measurements had been done by using the same excitation procedure for the main coils. The field distributions along the radius were mapped at 10 field levels at the excitation current of 300, 400, 500, 600, 700, 800, 900, 1000, 1100 and 1200 A. And at same field levels the contribution of the trim coils were measured. Especially we made efforts for measuring the contribution of plug at some magenet field levels and tried to obtain the optimum value. The measurement accuracies is ± 2 Gauss. The deviation between the required isochronous field distribution along the radius of $Ar^{8+} - 2.345 MeV/A$ and measured one is 5×10^{-4}. We measured the three-dimensions field distribution at the center region from 0 to 45 cm along radius and along axis by using 10 pieces of hall probe at field levels of 800 A. The magnet field distribution in the hole of yoke along axis had been measured at field levels of 300, 800 and 1100 A. The edge magnet field distribution along exraction direcion at some field levels also had been measured.

At same time the Dee and dummy Dee was rebuilt to match the external injection system. The electrostatic deflector was replaced by new one to increase extraction efficiency. Two HIRFL-800 cryopumps took the place of two oil diffusion pumps. And the microcomputer-CAMAC system is used to control the SFC and the beam line.

6. COMMISSIONING

The commissioning was started in May. $Ar^{8+} - 2.345 MeV/A$ was accelerated at 3rd harmonic. ECR ion source worked stably. The transportation efficiency of beam line from ECR ion source to the inflector is better than 60%. When the main magnet field of 50 Gauss was decreased and the angle of 2° of inflector was tuned, the beam reached the extraction radius. The extraction efficiency of electrostatic deflector is better than 60%. Then Ne^{4+} was accelerated smoothly. These are just initial results.

7. REFERENCE

1) B.W.Wei, Z.W.Liu, etc.,"Study on the magnetic field of CAPRICE type ECR ion source," this conference.

2) J.Z.Jiang, X.H.Zhou, etc.,"Buncher in the beam line from ECR to SFC," this conference.

3) J. Belmont, "Axial injection and central region of the AVF cyclotron," **Lecture Notes of 1986 RCNP KIKUCHI Summer School on accelerator Tech.**,1986.