FIRST OPERATION OF THE ECR ION SOURCE AT THE INS SF CYCLOTRON

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ABSTRACT

An ECR ion source for multiply-charged heavy ions and a beam injection line have been installed at the INS SF cyclotron. Their combined performance has been tested since August, 1989. Several kinds of beam from the ECR source were injected into the SF cyclotron and successfully extracted. Typical overall transmission efficiency of 3.4% from the source to the external cyclotron beam has been obtained. An $^{16}O^{6+}$ beam has been used for experiment in nuclear physics. The construction and the first operational results of the ECR source and the beam line are described.

INTRODUCTION

The SF cyclotron is a variable energy three-sector single-Dee machine[1]. It has a K number of 68 and the maximum magnetic field, 16.4 kG. The rf voltage between 20 and 60 kV is used, and the frequency, from 7.5 to 22 MHz.

The axial injection system was used for the polarized ion source only. A new beam injection line was designed in order to deliver the beams from both the ECR and the polarized ion source[2]. The cyclotron is now equipped with the internal PIG source for light-ion operation, and the external sources, the ECR for heavier ions and the polarized ion source. Ions from ECR source are axially injected into the cyclotron. The dee voltage of the cyclotron is required to be about 5.7 times of the injection voltage from the condition of the orbit centering in the cyclotron.

The test operation of the ECR source was started in May, 1988 at the test stand. Now the reliability of the source has been much improved. The source has been operated with gaseous elements from ^{12}C to ^{40}Ar.

ECR SOURCE

The source consists of two ionization stages and is basically designed to be operated by forming closed ECR zone for each stage. The first operation at the cyclotron was carried out by forming one closed ECR zone at the second stage and one open ECR zone at the first stage[3].

The axial magnetic field is produced by solenoid coils consisting of ten pancakes. They are divided into three groups; two groups with three pancakes and one with four pancakes can be individually excited to optimize the profile of the axial magnetic field. A shaping iron is placed near the exit of the first stage to increase the mirror field. In the first stage a quartz tube with a diameter of 10 mm was used, into which gas was fed. The ECR surface is not closed in the first stage.

In the second stage a set of $SmCo_5$ hexapole magnet was installed to cofine the plasma radially. The solenoid and hexapole magnet in the second stage produce the usual minimum B configuration.

The microwave power of 6.4 GHz with a maxmum power of 3 kW was fed into the second stage only. The extraction voltage is varied from 3.6 to 10.8 kV according to the injection condition to the SF cyclotron. The extraction hole is 10 mm in diameter, and the gap between the extraction hole and extraction electrode can be adjusted over a range from 20 mm to 40 mm.

The performance of the source is described below.

BEAM INJECTION LINE

The beam injection line was constructed in this summer. The line is made of a doubly focusing 100-degree analyzing magnet, four quardrupole magnets, two 45-degree bending magnets, two pairs of solenoids and an electric quardrupole triplet, as shown in Fig. 1. The Table 1 gives a more complete description of the line.

The system was designed to transport beams with a maximum magnetic rigidity of about 32 kG・cm, although the maximum $B\rho$ acceptable by the electrostatic mirror-SF cyclotron system[2] is 25.4 kG・cm.

A double-gap buncher is installed at 3.5 m upstream from the cyclotron median plane, and to the center electrode is applied a sinusoidal wave of the cyclotron frequency of upto two hundred volts.

The electrostatic mirror used for inflection of the beams into the cyclotron median plane is tilted to the incident beam by an angle of 46 degrees and has a 3 mm gap between the electrode and the grounded mesh.

The design parameters of the injection line was optimized using the emittance matching calculations for beam injection through the axial hole (hole lens) to the mirror exit. The calculations were done with computer code SFINJ based on the analysis in ref. 4.

Two sets of movable 4-jaw collimator in the analyzing system and five Faraday cups are provided near the beam waist positions. Small steering magnets are used to correct for the effects due to the 5-15 Gauss cyclotron leakage field at a few locations along the line.

The vacuum pressure in the beam line is designed to be $5*10^{-7}$ Torr using three 300 l/s turbopumps.

The assumed emittance was 200π mm・mrad in both planes. These values are about the same as the acceptance of the electric quardrupole triplet. Fig. 2 shows the envelopes of the beam in both transverse planes, as calculated with the TRANSPORT. Waist-to-waist focusing was used throughout.

Table 1. Summary of Beam Analyzing System and Beam Line Elements.

Assumed Beam at object slits	±5mm×±40mrad, x and y
Drift to 100° magnet	67.5cm
100° magnet	ρ=35cm, B=1.2kG(I=100A) edge angle=34.5°
Drift to image slits	67.5cm magnification∼1 Resolusion 160 for momentum 80 for m/q
Quadrupole magnets	G=0.3kG/cm(I=50A) pole length=10cm pole gap=10cm
45° magnets	ρ=30cm, B=1.4kG(I=100A) edge angle=15.9°
Solenoids	20cm length B=1.5kG(I=100A)
Electric Quadrupoles	pole length=18cm pole gap=5cm V=±150∼±350V(usual)

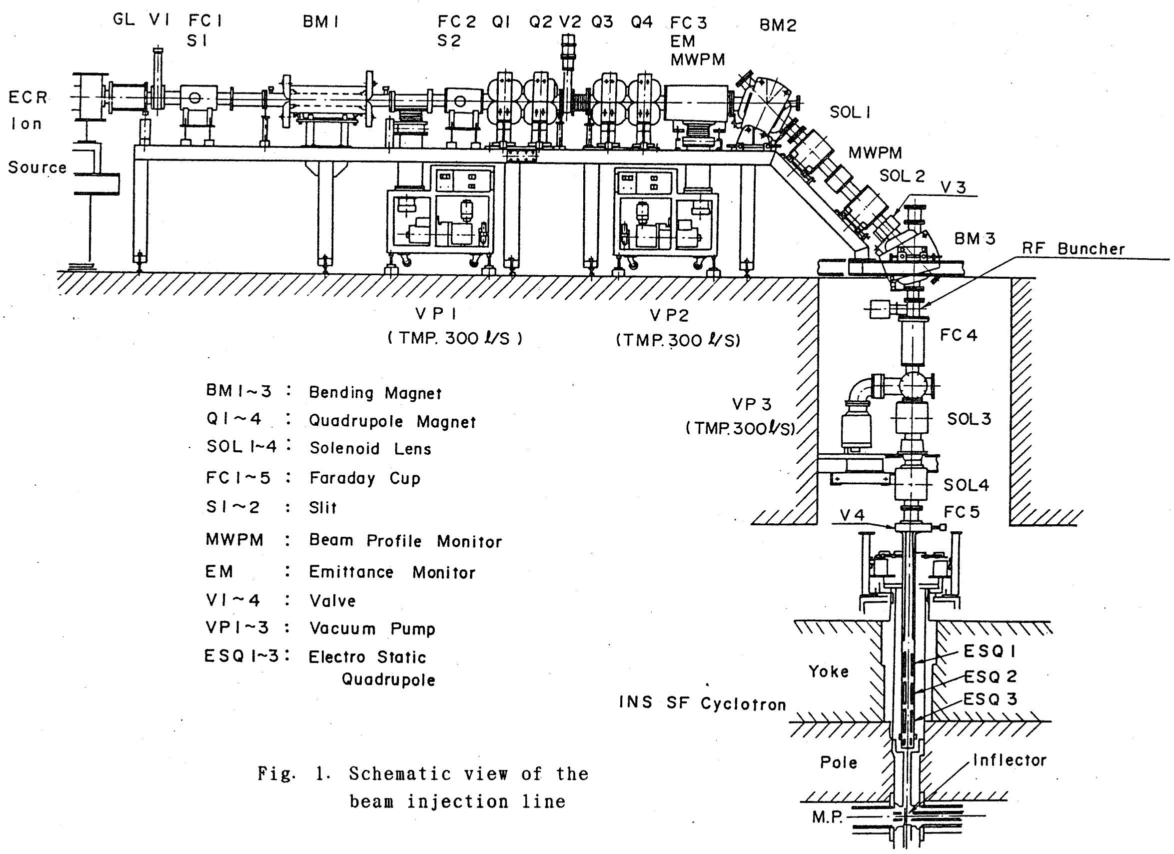


Fig. 1. Schematic view of the beam injection line

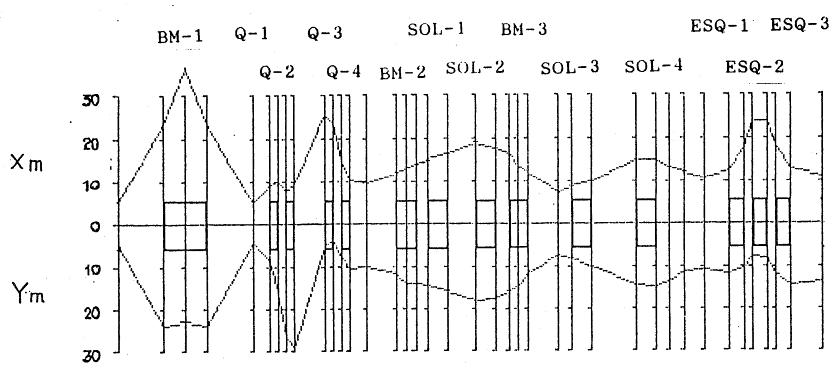


Fig. 2. Beam envelope along the injection line, calculated 20Ne6+beam; B ρ =26kG・cm.

PERFORMANCE AND RESULTS

The source has been operated for about one year, including performance test at the test stand. In Table 2 are listed the typically extracted beam currents and ionic species from the ECR source upto now. All the results were obtained for the slit widths of 20 mm at the object and 10 mm at the image of the analyzer, and at the extraction voltage of 10 kV.

Gases were mixed and fed into the first stage. Beams of carbon and oxygen were each produced from the gaseous compounds, CH_4 and CO_2, and pure gases were used for the other elements. For all elements, helium gas was added to enhance the high-charge-state performance of the source, except for Ar for which O_2 was added. With the combination of Ar + O_2, the beam intensity of $^{40}Ar^{11+}$ increased by about four times.

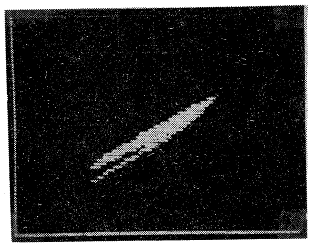
The operating pressure was typically $1*10^{-6}$ and $6*10^{-7}$ Torr at the second and the extraction stage respectively. The maximum rf power fed only to the second stage did not exceed about 500 W and the drain current was generally between 0.5 mA and 1.5 mA. Typical power consumption of the solenoidal pancakes is 30 kW.

Fig. 3 presents horizontal(X) and vertical(Y) emittances of $^{20}Ne^{6+}$ beam, at 95% maximum current. A typical spectrum obtained with Ar is shown in Fig. 4. Ar ions with up to 14+ charge state are observed.

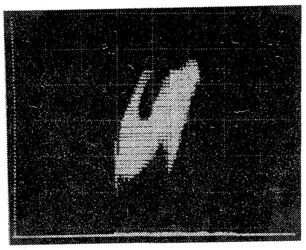
The beam injection and acceleration tests were carried out at near the maximum and at medium magnetic field strength of the cyclotron. The transmission efficiency of the beam from the ECR to the cyclotron exit was found to depend on the field strength; for example, overall efficiencies were about 2.4 % and 3.4 % at 16.2 kG, and at 13.5 kG, respectively. These values of the efficiency are not satisfactory compared to the designed value. The beam losses in the system occur mainly at the initial stage of acceleration process in the cyclotron. To increase the beam transmission further improvements are planned.

Table 2. Extracted beams from INS ECR source

ION	Ext. Current from ECR (eμA)	ION	Ext. Current from ECR (eμA)
C^{4+}	83	Ne^{3+}	51
C^{5+}	19	Ne^{4+}	56
		Ne^{6+}	33
O^{2+}	85	Ne^{7+}	12
O^{3+}	90	Ne^{8+}	4.5
O^{5+}	52	Ne^{9+}	0.23
O^{6+}	33		
O^{7+}	3.2	Ar^{6+}	45
		Ar^{7+}	39
N^{3+}	45	Ar^{8+}	47
N^{4+}	39	Ar^{9+}	35
N^{6+}	6	Ar^{11+}	3.4
		Ar^{12+}	0.5
		Ar^{13+}	0.15
		Ar^{14+}	0.04



Ex=210 π mm・mrad
x_{max}=18mm
x'_{max}=30mrad



Ey=180 π mm・mrad
y_{max}=12mm
y'_{max}=20mrad

Fig. 3. Emittance of $^{20}Ne^{6+}$ beam, a)in horizontal and b)in vertical

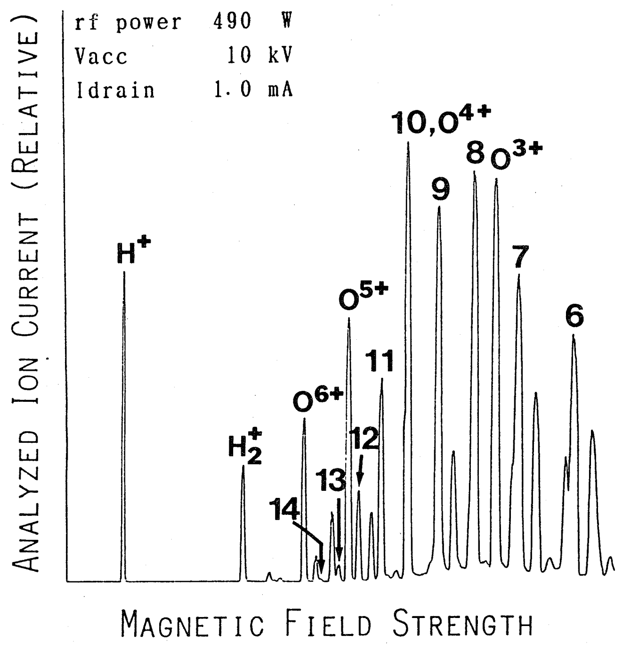


Fig. 4. A spectrum of Ar beam from ECR ion source, tuned for Ar^{11+}

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