

## PRESENT STATUS OF THE SF-ECR ION SOURCE FOR THE SF CYCLOTRON

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### Abstract

A conventional 6.1 GHz ECR ion source (SF-ECR) has been used as an ion source for the SF-cyclotron at Center for Nuclear Study (CNS), School of Science, University of Tokyo. While it has been routinely operated, this source has just been modified to upgrade its capability. The point of the modification is that output beam current of highly charged ions be increased by strongly confined hot electrons in the plasma. In order to achieve this goal, we replaced an old sextupole permanent magnet with a new stronger one as well as the steel configuration was modified so as to enhance the mirror magnetic field. The performance test by using the new sextupole and the high-mirror field configuration is under way.

### 1 Introduction

The use of an ECR as an external ion source to the CNS-SF cyclotron began in August 1989. Since then, 30 % of cyclotron operation for beam time on average has been carried out with this ion source. Multiply charged ion beams such as  ${}^6\text{Li}^{2+}$ ,  $\text{C}^{4+}$ ,  $\text{N}^{5+}$  and  $\text{O}^{6+}$  were successfully extracted and provided for various nuclear and atomic experiments. The overall performance of the ECR

source is excellent in terms of reliability, beam intensity and production of the high charge-state ions. Details of the operating characteristics of the SF-ECR ion source have been published elsewhere [1][2].

Recently, the beam time using higher-charge state ion beams such as  $\text{C}^{5+}$ ,  $\text{N}^{6+}$  and  $\text{O}^{7+}$  has grown larger. Their beam intensities, however, are now not high, namely, 12  $\mu\text{A}$  for  $\text{C}^{5+}$ , 18  $\mu\text{A}$  for  $\text{N}^{6+}$  and 6  $\mu\text{A}$  for  $\text{O}^{7+}$ . In order to increase the beam intensity of these ions, the following modifications are made up to now: (1) A sextupole permanent magnet is renewed to get a stronger radial field of the ECR zone. (2) Two iron field-shaping blocks and one iron yoke are added to enhance the mirror ratio of the magnetic field in this source.

We report here the design principles of the high-mirror ratio field configuration of SF-ECR in 6.1 GHz operation, and their characteristics details in the following.

### 2 SF-ECR ion source

Fig. 1 shows a schematic drawing of the modified SF-ECR ion source. Its original design was to allow a double stage operation. At present, however, only the second stage is used to yield sufficient beam intensities [1].

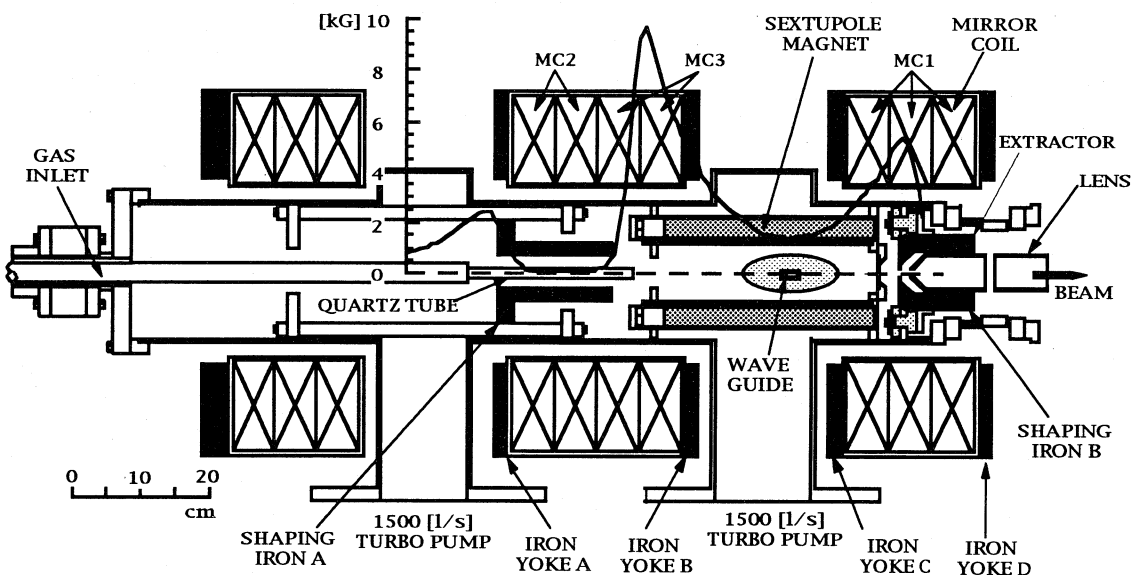


Fig. 1 Schematic view of the modified SF-ECR.

The mirror field is produced by a pair of solenoid coils: MC1 and MC2, and corrected by the coil: MC3. The radial field is produced by a sextupole permanent magnet inserted in the vacuum chamber. Thus a minimum B structure for the plasma confinement is formed by three coils and a sextupole magnet.

The RF power of 6.1 GHz is fed radially into the plasma chamber through a quartz RF window. The RF power was varied ranging from 100 to 500 W depending on ion species.

The plasma chamber is pumped directly from the radial direction by a 1500 liter/sec turbo molecular pump. A typical vacuum pressure of the plasma chamber during the production of high charge-state ions is about  $10^{-6}$  Torr. Two gas feed lines, one for the ions of interest and the other for a supporting gas, are connected to the plasma chamber. Since this source has a large vacuum conductance, it makes it possible to get swift recovery from bad vacuum pressure and to control gas element by a wide dynamic range.

### 3 Modification of Mirror field structure

In order to confine the electron strongly, the peak of the mirror field was enhanced. As shown in Fig. 1, an old field-shaping iron block A placed inside the vacuum chamber at the side of the coil MC2 was replaced with one which has double size in length, to increase the axial field around MC2. Also, at the beam extraction side, a field-shaping iron block B was nearly inserted to increase the axial field around MC1.

The use of these two field-shaping iron blocks could enhance both two peaks of the mirror field, and the minimum field in the middle of a axial mirror field line increased. To modify the minimum magnetic field structure, an ion yoke C is added at the side of the coil MC1.

Details axial magnetic field distributions by the old conventional and new modified magnetic structures are shown in Fig. 2. The maximum axial field around MC2 and MC1 are enhanced from 6.5 kG to 9.5 kG and from 2.8 kG to 5.4 kG, respectively.

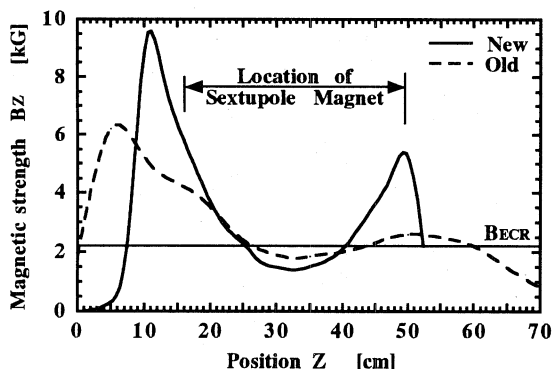


Fig. 2 Enhancement of the magnetic field on axis.

### 4 A new Sextupole magnet

In order to confine the electron, which is easily lost in the radial direction, the sextupole field should be enhanced.

A schematic drawing of a new sextupole magnet is shown in Fig. 3. The sextupole magnet is a compact assembly of Nd-Fe-B permanent magnets and is placed inside the vacuum chamber. Each pole is enclosed in a jacket to be water-cooled through the voids inside of the jacket. This sextupole magnet has the same bore and the same radial accessibility as the old Sm-Co sextupole.

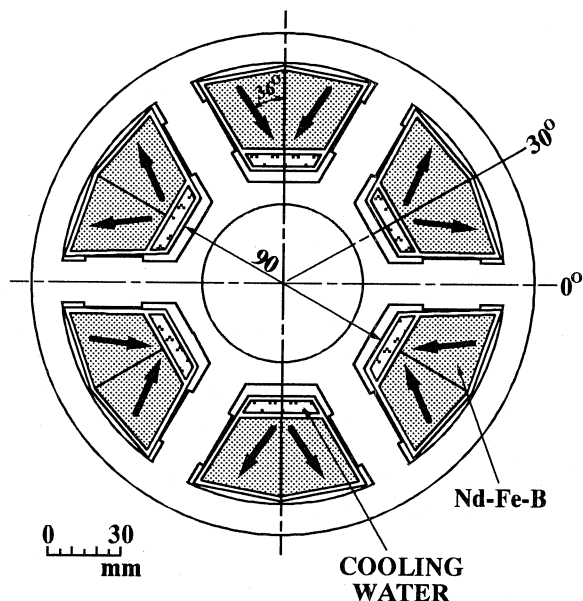


Fig. 3 Cross section of the new sextupole magnet.

The sextupolar field is produced by six sector pieces of Nd-Fe-B magnet which has a magnetic field flux of 36 degree span along the azimuthal direction. Distributions of the new and old sextupolar field measured are shown in Fig. 4, where the radial field strength  $B_R$  was plotted in ordinate axis of 5 mm along the axial direction in horizontal axis. The azimuthal angles of both 0 and 30 degrees were taken. By using the new sextupole magnet, the field strength on the jacket surface of the magnets was enhanced to 4.0 kG compared with the old one to be 3.0 kG.

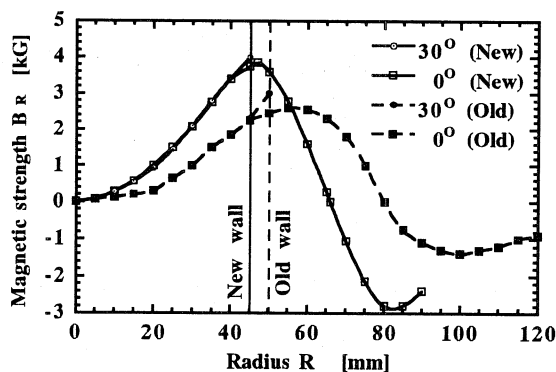


Fig. 4 Magnetic field of the sextupole magnets.

## 5 Extraction configuration

In order to increase the beam intensities after the analyzer of the SF-ECR ion source, the magnetic field produced by the mirror coil MC1 was adjusted slightly depending on the decrease of the beam intensities. It has been thought that the ion beam extracted from the source is focused by the magnetic field outside the mirror coil MC1. Since this field became small due to the insertion of the field-shaping iron B, a focusing element is added just behind the field-shaping iron B.

The distance between the extraction electrode and the anode plate is 30 mm. The diameter of the extraction electrode hole is 12 mm, and that of the anode hole is 8 mm.

## 6 Conclusion

The specification of the modified SF-ECR is shown in Table 1. The vacuum chamber has a large volume cylindrical structure which go through the each solenoid coil, so, magnetic field structures can be easily modified by inserting field-shaping iron without change of the other elements.

Table 1. Specification of the modified SF-ECR Ion Source.

Magnetic field	
Typical solenoid current	MC2 : 500 A / MC1 : 360 A
Typical field on axis	9.5 / 5.4 kG
Mirror ratio	6.0 / 3.5
Sextupole material	Nd-Fe-B
Sextupole length	340 mm
Sextupole inner diameter	90 mm
Sextupole field on surface	4.0 kG
Microwave system	
Frequency	6.1 GHz
RF power	100~500 W
Plasma chamber	
Chamber inner diameter	90 mm
ECR zone length	150 mm
ECR zone diameter	55 mm
Beam extraction	
Extraction voltage	4.0~12.0 kV
Anode hole diameter	8 mm
Gap between anode and extractor	30 mm

In order to increase the beam intensity, the following improvements were made : (1) By using the new Nd-Fe-B sextupole permanent magnet, the field strength on the surface of the magnet vessel was enhanced to 4.0 kG. (2) Since two field-shaping irons and one iron yoke are added, the mirror magnetic field around MC2 and MC1 were enhanced to 9.5 kG and 5.4 kG, respectively.

From these results, a typical size of the ECR surface is expected to be about 15 cm in length and about 5.5 cm in diameter. And the value of the mirror ratio around MC2 and MC1 became 6 and 3.5 times, respectively.

The performance test by using the modified source is under way.

## References

- [1] M. Oyaizu and Y. Ohshiro et. al., Proc. 10th Int. workshop on ECR Ion Source, ORNL Report CONF-9011136, ed. F.Meyer, 1991, p25.
- [2] Y. Ohshiro, M. Fujita and H. Muto et. al., Proc. of the 12th International Workshop on ECR Ion Sources, April 25-27, 1995 RIKEN, Saitama 351-01, Japan. (INS- Rep.-1104 July, 1995).