STUDY ON THE MAGNETIC FIELD OF CAPRICE TYPE ECR SOURCE

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ABSTRACT

The magnetic field modification and source test are presented. A preliminary test on a cold cathode used for the second stage of CAPRICE is reported.

1. INTRODUCTION

The HIRFL injector cyclotron SFC is a K69 energy variable multiparticle one-Dee machine.Originally,a radially inserted PIG source was used as its internal source. To increase significantly beam energy ,variety of ion species, operation efficiency and reliability,an ECR source has been coupled to SFC as an external source. HIRFL then will be able to accelerate ions from C to Ta upto energy of about 120 and 7.5 MeV/A respectively. The ECR source is a CAPRICE type introduced from CENG.Lab. France in 1988. Over the next year the source worked on IMP test bench.During this time a test on the magnetic field modification was carried out. In 1990 an atomic physics experiment using the high Z ions from CAPRICE was performed [1]. At the end of 1991 CAPRICE was coupled to SFC by a injection beam line. Some more tests on the source were done also. Recently,another CAPRICE -like source was designed and machined. Now it is assembled and ready for tuning.

2. CAPRICE ION SOURCE

The 10GHz ECR source CAPRICE is a very compact source suitable for producing high Z ions of gaseous and solid elements [2-3]. As it is shown in Fig.1,only one microwave generator is used for both first and second stages. The microwave is fed from waveguide 6, passing through microwave window 11, the coaxial line around the first stage,and finally is fed into the multimode cavity 12. A cold dense plasma is ignited inside the quartz tube 14 ,then diffuses into the second stage,where the working gas pressure is much lower and a good magnetic confinement is produced by the combination of the axial field and the hexapole field.Even more,a closed ECR surface can promotes to produce plasma electrons of Kev energies. The main features of CAPRICE source are:

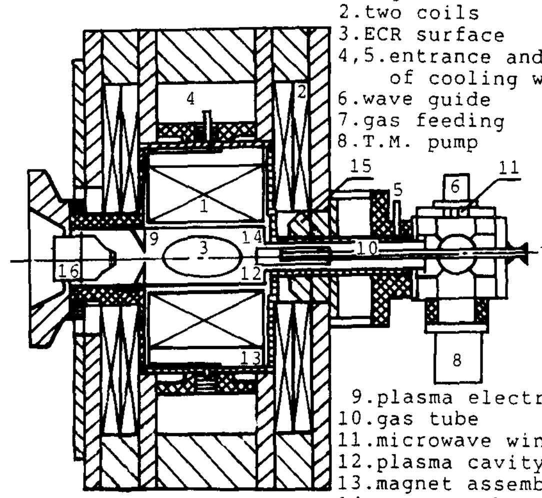


Fig. 1. CAPRICE.

(1) The solenoids are shielded with iron flanges on both sides and the hexapole is surrounded by an iron cylinder, which are helpful to decrease the electric power consumption in the mirror solenoids.
(2) Some iron parts are used to form the needed magnetic field. This makes the source compact,especial short distance between the two stages and between the ECR zone and extraction hole. As a result, a better diffusion of plasma from first stage to second stage and high extraction current are achieved.
(3) There are no pumps, no microwave window in the main stage. The plasma cavity is all in one piece for both stages. It is easy to be assembled and disassembled. These features make CAPRICE source convenient for operation, tuning and maintenance.

3. SOURCE STUDY ON TEST BENCH

CAPRICE had been well tuned at CENG. Lab.typically for oxygen ions with excellent result,and then was also tuned on IMP test bench. The result showed the extracted ion currents were essential the same as got in CENG. This implied the good reproducibility of the source and that the supplementary equipments disposed in our Lab. worked normally.

To satisfy the needed ion yields for heavy elements, we tried a possible modification of the source. As we can see in Fig.1,a conical iron ring 15 plays an important role for the formation of first magnetic mirror peak. The position of this ring can be adjusted along the axis and optimized for each ion species. Based on the magnetic field calculation,a more suitable ring shape was found out. Figure 2 shows the original iron ring and new one,while in Fig.3 the magnetic field B on the source axis is given for these two cases. It can be seen that this new ring provides a higher peak value and narrower width. The results of ion yields for Ne,Ar and Xe for both the original and new shaped conical ring are presented in Tab.1. A considerable increasing in extracted currents with factors of about 1.5 and 2 is got for Ne and Ar ions respectively. Figure 4 shows the ion-spectrum optimized for Ar^{8+} with He as a supporting gas. It is worth notice that the benefit is mainly based on the improvement of the CSD (charge state distribution) in plasma.

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

* Data on left-top are for original ring

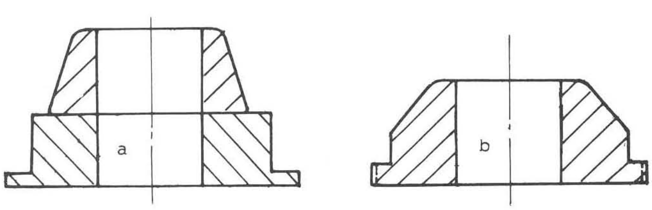


Fig.2. The shape of original ring (a) and new ring (b)

As it is shown in Fig.3,the new iron ring makes the mirror peak a little narrow,and so the first resonance point closer to the second stage. In this case a certain increment of the injected plasma from first stage is got. This plasma contains mainly low Z ions. It is helpful in igniting and sustaining plasma in second stage at a lowest possible neutral gas density. Therefore, the loss rate from charge exchange,especially for higher Z ions,is reduced, and better CSD can be expected. On the other hand, this new mirror peak with higher peak value may drive the plasma in second stage to be concentrated into the area near extraction hole.

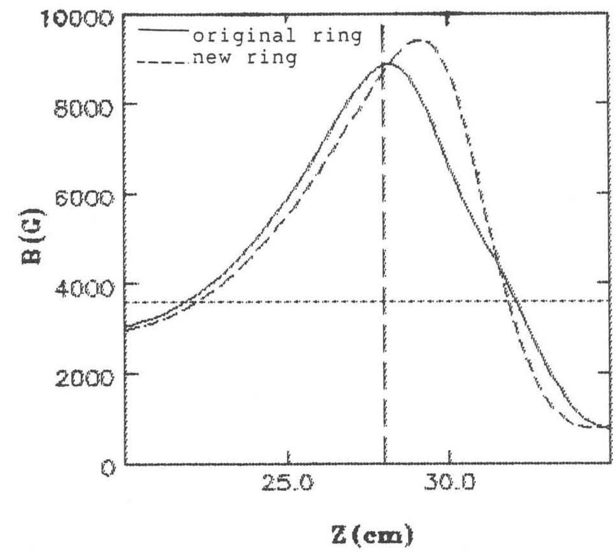


Fig.3. Magnetic field B along source axis. Coil current $I_1 = 1120A, I_2 = 1110A$.

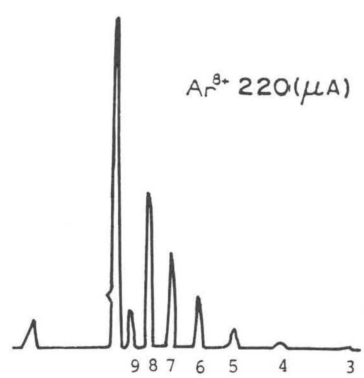


Fig.4. Ion spectrum optimized for Ar^{8+}.

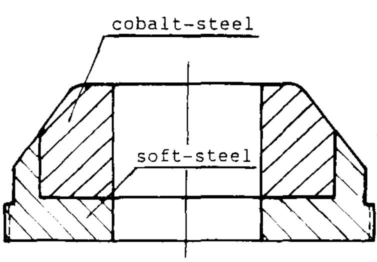
4. SOURCE OPERATION WITH INJECTION BEAM LINE

When CAPRICE was coupled to the injection beam line of SFC,the source had to share high pressure cooling water with other elements of the beam line.It proved that the cooling water pressure for solenoids of CAPRICE is lower than it should be.Meanwhile,the coil currents for solenoids usually exceeded 1100 A, and these were very near to the upper limit of the power supplies.The only feasible solution is to decrease the electric power consumpion in the solenoids without any losses in the extracted beam. After the calculation of the magnetic field distribution inside soft-iron elements of the source, we found that some of them were saturated very much. In this case three options have been taken.

(1) Changing the material of the conical ring from soft iron to cobalt-steel with much higher saturation magnetization. Figure 5 shows the cross section of the new ring. It is expected to increase the first mirror peak by this change.

(2) Putting a soft-iron flange attached to the end flange at source extraction side. It should be responsible for the increasing of the second peak value.

(3) Using a puller with a special structur as shown in Fig.6. It consists of two parts,stainless-steel and soft-iron for each. Figure 7,8 show the magnetic field B distributions,especially in the extraction side, for the original stainless-steel puller and the new one with optimized coil currents for both solenoid groups.



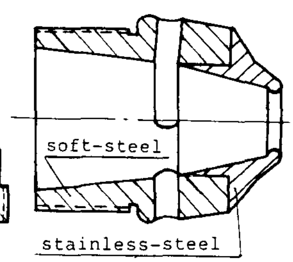


Fig.5. New conical ring with cobalt-steel.
Fig.6. New puller with two kinds of material.

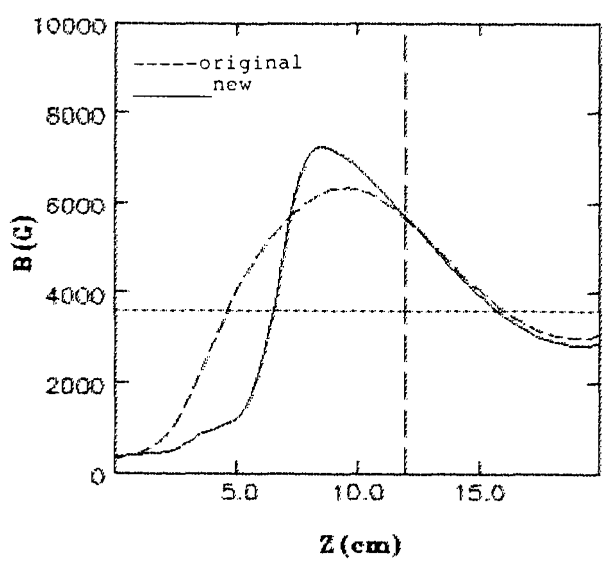


Fig.7. Axis magnetic field near the extraction. Original: $I_1 = 1120A, I_2 = 1110A$. New: $I_1 = 1062A, I_2 = 974A$

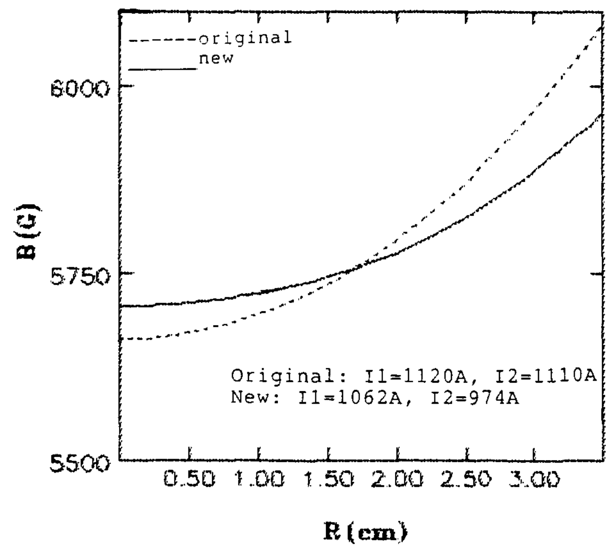


Fig.8. Magnetic field vs radius near the extraction.

In Fig.7 the curve is refered to B data along source axis. while Fig.8 is for the total mirror B data along a radius at the axial position of a few mm before the extraction hole. It can be seen that new puller gives a better field configuration with magnetic fields appropriately increased both on the source axis and on the large radius at the extraction region.

After all these changes, the magnetic field B on the source axis is shown in Fig.9. The source is then operated with a satisfactory result. The average electric power consumption for solenoids is decreased by 10% for the injection side and more than 20% for the extraction side. In addition,the gas feeding is decreased remarkably. The benefit in Ar^{8+} beam current of approximate 20% is achieved.

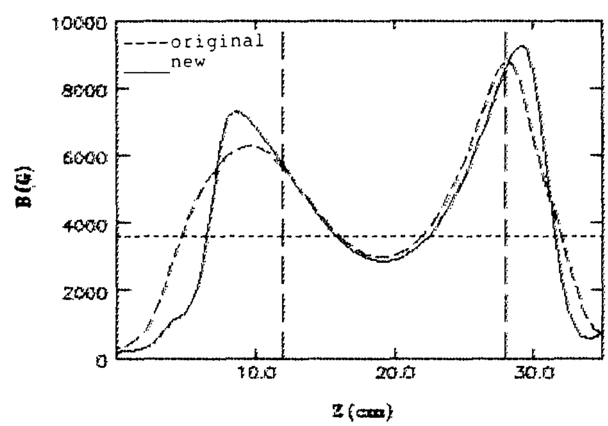


Fig.9. The final B along source axis after change. Original: $I_1 = 1120A, I_2 = 1110A$. New: $I_1 = 1062A, I_2 = 974A$

5. PRELIMINARY TEST ON A COLD CATHODE FOR ECR SOURCE

Under the inspiration of using a electron gun for ECR at LBL [4],a study on the use of a cold cathode for CAPRICE type source has been carried out. Figure 10 shows the schematic drawing with a cold cathode of position-adjusted along the axis by a piece of permanent magnet.

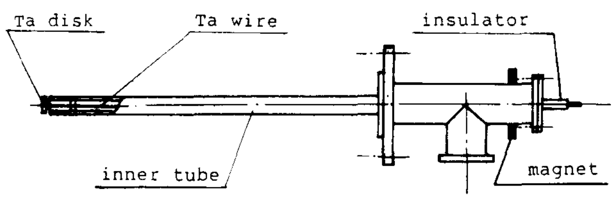


Fig.10. The cold cathode for CAPRICE.

Using this method only Ar^{8+} was tested for the ready optimum parameters of the beam line from CAPRICE to SFC. All the data quoted below for beam current are in microampere and measured at the third faraday cup, which is located in the position about 1 meter before the bottom of SFC and about 6 meters from the source.

The source was operated in the following cases:

(1) The source worked in the ordinary fashion with two stages. Beam current was about 140.

(2) Using single stage mode and extending the inner coaxial tube into the second stage. Beam current decreased to 70.

(3) The source was operated in the fashion similar to that as shown in Fig.10,but without the Ta disk. In this case,Ta wire of 1mm in diameter was used. Beam current came up gradually until 135 when the negative voltage increased upto 800 volts.

(4) Using the cold cathode as shown in Fig.10. When the biased negative voltage was only put to about 10 volts, beam current increased considerably and then reached to saturation condition. Beam current could get the maximum of 240 when the biased voltage was about 50 volts negative. That meant about 70% increasing of beam current in this case than the usual case 1. The operation parameters of the source were changed much. The optimum microwave power was decreased from the ordinary value of 500 watts to 360 watts. The gas feeding was critical and decreased obviously.

The increasing of ion current is attributed to the extra directional electron emission from the Ta cathode. These primary directional electrons from the disk are mainly concentrated around the source axis. This makes a favourite increase of the plasma density around the axis. In this case,as it is pointed out [4], an additional electrostatic trap may be got.

In principle, the emission area of the cathode is important. From the results of case 3 and case 4, we may deduce that with proper increasing of the emission area of the cathode, a more benefit could be got.

In addition, for the single stage operation mode the magnetic field configuration must be slightly changed. To reach the maximum magnetic field near the end of coaxial feeder, the conical iron was found 10mm into the source body by calculation and experimentally.

Until now, we have not yet made the source to produce metallic ions. According to the test in the case 3, it may propose a possible method of metallic material feeding for metallic ion production. In this case,instead of sample position adjusting by a mechanical way,a biased voltage adjusting is possible for tuning the sample feeding in a accurate way.

6. CONCLUSION

During our tests and operation with beam line, we found CAPRICE is an efficient source,though our source has only a 0.4 T permanent hexapole. Based on the magnetic field calculation we have made some magnetic structure innovations for CAPRICE. At the moment the maximum Ar^{8+} ion current extracted from the source is estimated to be 350 microampere or more when a cold cathode is used.

7. REFERENCES

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