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DESIGN OF THE INS ECR ION SOURCE

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Abstract

An ECR ion source for the mutiply-charged heavy ions has been designed and is being manufactured for the INS SF cyclotron. It is to produce the beam in the next spring. After some performance tests at the RFQ linac, TALL, it will be installed at the cyclotron. The main features and the design concept are described.

INTRODUCTION

In many cyclotron laboratories, ECR ion sources have been introduced successfully and are now commonly used for production of multiply-charged heavy ions. They are now one of the indispensable components of the cycotrons for heavy ion uses.[1]. In addition, these sources are coupled not only with the cyclotrons, but to other types of accelerators[2] and are used by themselves as sources of highly ionized ions.[3]

Stimulated by these success we have designed an ECR source for the INS SF cyclotron. The SF cyclotron has a K number of 68. Since the maximum magnetic rigidity of this machine is not so large, the gain of energy by raising the charge states of the accelerated ions is not large. Rather, according to the reports[4], the advantages of the ECR sources over the PIG sources are the stability and efficiency of operation, thus resulting in the overall improvement of utility of the cyclotron facility. We expect mainly this feature.

A comparison of the energy and intensity of the beams of the ions extracted from the SF cyclotron is shown in Fig. 1 for the ECR and PIG sources. An ECR source with the same performance as the one at LBL 88" cyclotron is assumed.[4] The transmission efficiency from the source to the extraction is assumed to be 5 %. Intensity of the PIG source, now in use at the SF cyclotron, is the one attained at this cyclotron.[5]

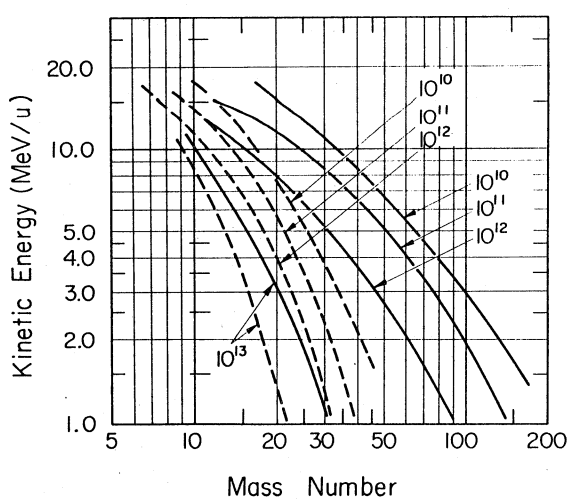

Fig. 1 Energy and intensity of the extracted beam from the SF cyclotron as a function of the mass number of the ions. The dashed curves represent those obtained with a PIG source and the solid curves are those expected from an ECR source. The numbers are the beam intensity in the unit of particles/sec.

The mass number of the ions obtainable with our cyclotron with good intensity and energy is around 50, if the performance assumed in the Fig. 1 is achieved. The goal of this source is, therefore, around this mass number. The minimum charge-to-mass ratio of the ions acceptable to this cyclotron through the axial injection line at about 10 keV/u, is about 1/7. This figure is another goal of this source.

In spite of the great progress already made by the pioneering workers, the basic processes underlying the ECR sources are still to be studied. This may be understood if one looks at the ever increasing performance in many laboratories in these years.[1] In our design, as the second aim, it is intended that this design could set a base for further improvement of the ECR source performance by studying the physical processes for production of multiply-charged heavy ions.

In addition to the SF cyclotron, another accelerator, an RFQ linac, TALL, requires a heavy ion source. This could be a useful machine if a good ion source is added. It accepts ions with the charge-to-mass ratio above 1/7 at the energy of 8 keV/u and accelerates them upto an energy of 800 keV/u. In our design, we took into considration of the study of coupling the ECR sources to RFQ linacs.

SELECTION OF THE MICROWAVE POWER SOURCE

As is well known, the cut-off frequency of the electomagnetic wave in a plasma limits the density of the plasma produced by that wave. In an ECR ion source, if one desires to increase the plasma density, the frequency should be higher. However, since a microwave power source of a few kilowatts is necessary, the availability, cost and technology are the important factors. We have investigated various factors and have determined to purchase a commercially available microwave transmitter, VARIAN VZJ-2700. It can supply maximum power of 3.3 kW, which is divided into 1:3 for the first and second stages. A block diagram of the micowave source is shown in Fig. 2 and the specification of the transmitter is listed in TAble 1.

Table 1 Specification of the VARIAN VZJ-2700 transmitter

Frequency Range	5.85-6.45GHz
Frequency Stability	$<1.0\times10^{-6}$/min
Output Power	>3.1 kW (CW)
Output Power Stability	<0.5%(Short Time)
	≤1.0%(Long Time)
Harmonic Output	<-35dBc
Total Gain (Pre Amp+Klystron)	>77dB
Beam Voltage	8.25 kV(DC)
Beam Current	1.10 A
HPA Model No.	VZJ2700H127(Varian Co.,LTD)

Once the frequency of the microwave is determined, the minimum diameter of the vacuum chamber follows. The chamber plays the role of a multimode cavity and the diameter of the cavity should be at least a few times larger than the wave length of the microwave if the cavity is to work as the multimode cavity. We have chosen a diameter of 216 mm.

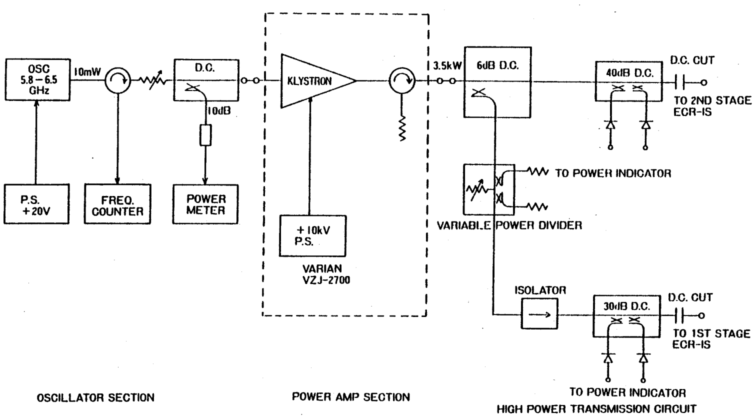

Fig.2 Block diagram of the microwave system

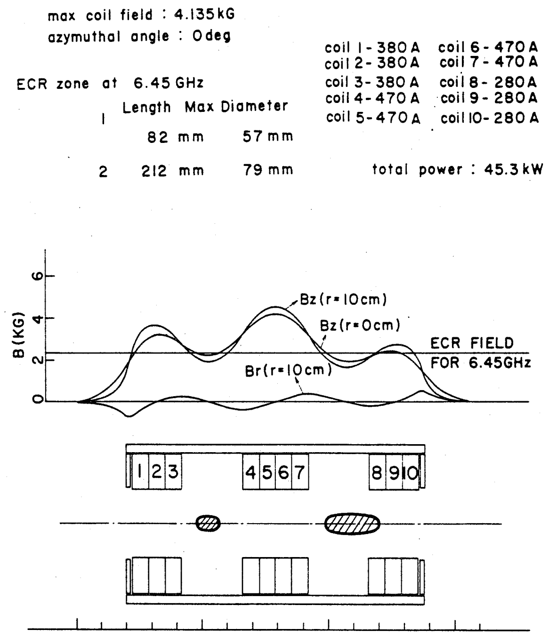

Fig. 3 Positions of the ECR zones and the shape of the mirror fields.

MAGNETIC FIELDS

The magnetic field plays the three important roles in an ECR ion source : 1) it provides the magnetic field for acceleration of electrons by micowave electric field, 2) it confines the ions and high energy electrons, 3) ions are transported along the magnetic field lines of force, therefore, the magnetic field guides the ions from the first stage into the second stage and from the second stage, out of the chamber. In this respect, we considered the distribution of the magnetic field is the most important factor for efficient production of the ions in the high charge states.

Once these are taken into account, since the difference between the first and second stages are only in the working gas pressure, we designed the same magnetic structure for both the first and second stages.

In this design, the B minimum structure is employed for both the first and second stages. The mirror field is produced by three coils. The two edge coils consist of three pancakes and the middle coil consists of four pancakes. By adjusting the current through each pancake, the field distribution can be changed rather widely. In addition, two plates can be attached to the both sides of each coil so that the mirror ratio can be also changed. The return yoke is four bars which support the coils.

Multipole field is produced by the permanent magnets of $SmCo_5$ arranged in the sextupole configuration. The length of the permanent magnet is 33 cm. The strength of the field can be varied by changing the distance of the permanent magnets from the axis. Small pieces of the permanent magnets are packed in a can through which cooling water flows. Six cans are mounted on a frame.

The microwave power is injected radially through one of the six slits between the permanent magnets.

An example of the ECR zone produced by these magnetic structure is shown in Fig. 3. The mirror field and the multipole field are calculated by the codes TRIM and PANDIRA, respectively, which were superposed to constitute the B minimum structure.

VACUUM SYSTEM

In order to obtain high intensity ions in the high charge states, the gas pressure and the vacuum of the chamber are important factors. The density of the neutral atoms should be low enough to avoid the charge exchange collisions of the ions in the high charge states with the neutrals, while in the first stage the neutral atoms should be much enough to maintain the discharge and yield enough amount of ions in low charge states. Thus the differential pumping is unavoidable.

In this design, a vacuum pressure of 10^{-7} Torr is aimed without gas load. Under the gas load of maximum 0.5 cc/min, the working pressure are designed to be 10^{-3} and 5×10^{-7} Torr for the first and the second stages, respectively. Two turbo-molecular pumps are used to achieve these working gas pressure by differential pumping. Between the first and second stages, an orrifice is set to make the conductance smaller. A ceramic pipe is inserted, in which the ECR zone of the first stage is to be produced, in the vacuum chamber for the first stage to reduce its volume.

EXTRACTION GEOMETRY

About 15 kV is enough for the injection energy for the cyclotron. In order to get some margin and for the test with the RFQ linac, an insulation capability of 40 kV is envisaged. The conductors of the coil are at the ground potential by insulating them with epoxy molding of the coils. The pusher plate and the extraction electrode are movable in order to adjust the distance between the ECR zone of the second stage and the extraction point.

The ion optical calculations are to be carried out further

SUMMARY

An overall view of the designed ion source is shown in Fig. 4. The ion source has a total length of about 1970 mm and its width is about 570 mm. The main design parameters are listed in Table 1.

The main parts are being manufactured. The source is expected to produce beams in the next spring. After some running tests at the RFQ linac, it will be installed at the SF cyclotron. The charge state analyzing system and the transport line to the center of the cyclotron are under design.

References :
1) R. Geller, Multiply charged ECR ion sources for particle accelerators, Proc. 11th Int. Conf. on cyclotrons and their applications (Ionics, Tokyo,1987) p.699
2) E. Minehara *et al*, Design of the ATLAS PIIECR ion source, *ibd.* p.725
3) F. W. Meyer, Operation of the ORNL ECR Source, Contributed papers of the 7th workshop on ECR ion sources, Julich, 1986, p. 10
4) C. M. Lynes, Operational performance of the LBL 88-inch cyclotron with an ECR source, Proc. 11th Int.Conf. on cyclotrons and their applications (Ionics, Tokyo, 1987) p.707
5) Y. Sakurada and T. Yamazaki, Acceleration of heavy-ion beams at the SF cyclotron, INS-J-168, 1984

Table 2 Design parameters of the INS ECR ion source

Microwave		
Frequency	5.85-6.45 GHz	
max.RF power	1st stage	0.75 kW
	2nd stage	2.25 kW
Multipole magnet		
Multipolarity	hexapole	
Field strength	3.0-0.6 kG	
Magnet material	$SmCo_5$	
Mirror coil		
Mirror ratio	1st stage	1.1-1.5
	2nd stage	1.3-1.8
Field strength	max.7.5kG (on axis)	
Power	max 100 kW	
Weight	1000kg(containing iron yokes)	
Extraction electrode	25kW	10 mA
Vacuum system		
pump		
1st stage	1500 l/s turbomolecular pump	
2nd stage	1500 l/s turbomolecular pump	
Vacuum		
1st stage	1×10^{-3} Torr(under 0.3cc/min gas loading)	
2nd stage	1×10^{-7} Torr(under 0.3cc/min gas loading)	

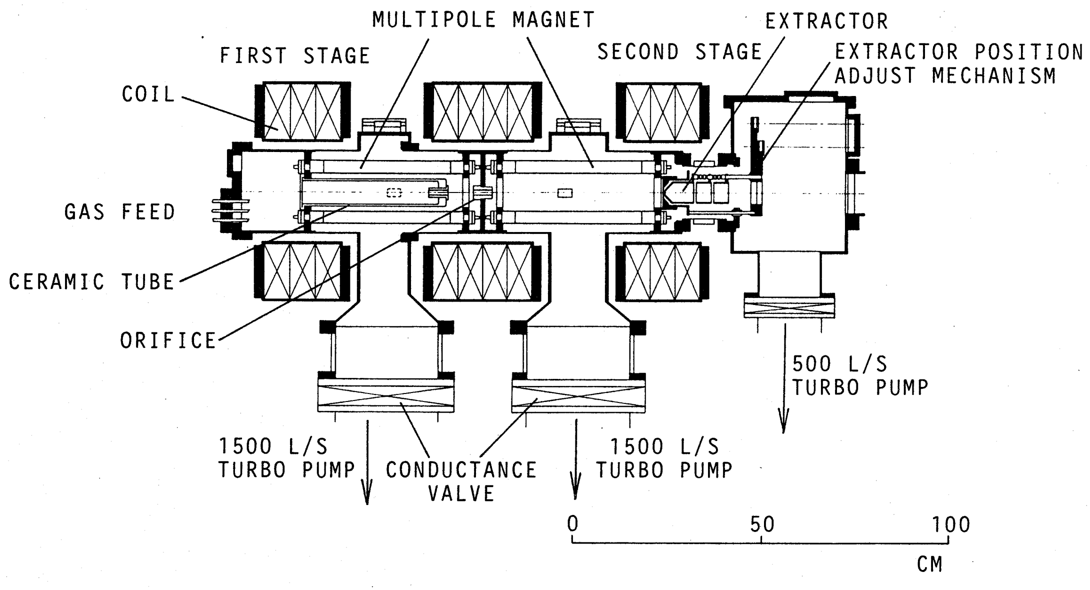

Fig 4 Schematic drawing of the INS ECR ion source