HEAVY ION ACCELERATION USING 224 cm CYCLOTRON AT KOLKATA

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Abstract

The cyclotron at Kolkata after accelerating light ions for twenty years was shut down in early 1997 for modification of the central region and connecting the 6.4 Ghz ECR source to the cyclotron. After carrying out several modifications and installation of the axial injection line the beam trials were started. The first heavy ion beam was obtained in early '98. Using oxygen as the test beam most of the initial debugging was done. Now the beams have been made available to the users for experiments. The second ECR ion source has been added to increase the range of energy and ion species.

1 INTRODUCTION

The 224 cm cyclotron at Kolkata (K=130) was commissioned way back in 1978. And ever since then it was used to accelerate proton, alpha and deuteron using a PIG source. The cyclotron was extensively used for nuclear physics, radiochemistry, radiation damage studies, isotope production and other related fields. During early 90's it was decided to accelerate heavy ion beams using an ECR source which had to be developed in-house. The development of ECR source was started initially with a two stage design. After a number of improvements in the source design the currents obtained gave us the confidence to inject into the cyclotron. Due to commitment to different user groups the cyclotron could only be shut down in early 1997 to make modifications in the cyclotron. Also the opportunity was utilised to make several major or minor modifications to different subsystems. Now the cyclotron is being used to accelerate light heavy ions and with the addition of a new ECR source the range of the species would be considerably increased. In future it is planned to provide beams to the Radioactive Ion Beam facility also using the high resolution line which are operable in achromatic mode.

2 MODIFICATIONS

2.1 Centre Region

The centre region modifications proved to be time consuming and difficult to carry out as it was decided to execute without lifting the poles. Specialised remote handling tools were used to attach the inconel dummy dee to the trim plate. The removable dummy dee inserts were fixed to the dummy dee using those tools. The dee inserts were mounted on the puller tray which earlier had the puller for PIG ion source. Fig 1 shows the dummy dee and dee insert installed The cooling lines were connected to the dummy dee. The probe track had to be modified to incorporate these changes and probes redesigned to intercept the beam as close as possible to the centre.

Figure 1.

A new centre plug in the top yoke was designed and installed for beam to traverse through it and accommodate a Glaser lens in the yoke.

2.2 Deflector

The cyclotron has entry and exit deflector spanning 108 degrees. For the light ions only entry deflector was used. Over the years the surface characteristics of the entry deflector had deteriorated resulting in problems of high voltage holding capacity. The entry deflector was replaced by a new set and the spark plates made of stainless steel were incorporated.

2.3 Vacuum

The vacuum system mainly consists of two 38" diffusion pumps with chevron baffles cooled to -40 ^{0}C. With a volume of 25 m^3 to evacuate and loads being added by use of epoxy resin feedthroughs for trim coils and neoprene cord used for sealing the flanges in the vacuum chamber the ultimate vacuum obtained in the acceleration chamber during light ion acceleration was 9.10^{-6} torr which was not adequate

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for heavy ion acceleration. The short term approach was to fix the real leaks by extensive leak hunting and modify coupling design in the resonator tank. Now the best vacuum obtained is 2.2×10^{-6} torr. Considering that this also is inadequate for higher charge states cryopanels have been tested with 80K cooling which will eventually have 20 K cooling. Even baffles are being planned to cool by liquid nitrogen. The pressure in the external beam lines have been improved to 5.10^{-6} torr.

3 ION SOURCES

3.1 ECR 1

The 6.4 Ghz ECR ion source (ECR 1) which has been indigenously developed is currently being used to inject beams into the cyclotron. First HI beams from the cyclotron were obtained using this source. The ion source intensity has increased substantially mainly by increase in the axial magnetic field. Also it has been possible to increase the extraction voltage from 8kV to 10kV. The supply of cold electrons and use of low mass mixing gas has improved the stability of the plasma considerably.

Table 1. The charge state distribution obtained from ECR 1 for 10 kV extraction and 8 mm aperture

CS	N	O	Ne	Ar
4	130			
5	86	120		
6	31	75	45	
7		12	25	
8			10	
9			1.5	41
10				
11				11.5
12				6.5

3.2 ECR 2

During the year 2000 another ECR source (ECR 2) was installed to augment the range of ion species and energies deliverable from the cyclotron. The first ion source was designed for gas feeds only. The major hardwares of this ion source was purchased from M/s Pantechnik, France. This is 14 Ghz source with metal feed provision also. The characteristic features are NdBFe magnet for sextupoles and coaxial feeding and is upgradeable to 18 Ghz operation. Presently the source is used for atomic physics experiment and very soon will be connected to the cyclotron. Table 2 shows the performance obtained with this source. With further development of beam parameters for different species resulting in better currents it is expected that the beams can be injected into the cyclotron for first harmonic acceleration.

Table 2. Charge state distribution in ECR 2.

CS	O	Ar	Xe	Pb	Ta
6	510				
7	110				
8	21	560			
9		362			
11		176			
12		100			
13		41			
14		18			
20			47		
21			46		
22			50		
23			51		
25			53	13	34
26			47		36
27			25	19	24
28			13	12	17
29			7	18	11
30			2	15	

4 INJECTION

4.1 Axial Injection Line

The beam from ECR1 is focused using two glaser lenses at the object point of 90^0 analysing magnet having 30^0 pole face rotation for vertical focusing. The beam is transported to the vertical section using six quadrupoles arranged in mirror symmetry. While four quadrupoles would have served the purpose six quadrupoles have been used so that beam matching can be done at the centre. The beam is bent by two 45^0 dipoles having three quadrupoles of unity magnification.

The beam from ECR2 is focused at the common point located at image point of 45^0section. The new injection line for ECR2 which will be installed very soon has been designed recently has a 90^0 charge analysing magnet followed by solenoidal transport section and another 90^0 magnet to bring the beam to the common point. The transport to the median plane is carried out using three glaser lenses the last of which is situated in the cyclotron yoke. The last glaser lens was fabricated using 6x6 mm^2 hollow copper conductor and 112 turns. As the space available is restricted the plugs made out of carbon steel serves as the return yoke for the lens. The focusing provided by this lens is adequate for first harmonic beams ($q/m>0.2$).The injection line is shown in Fig.2.

The buncher is of double drift type, driven by cyclotron frequency, and is placed at 1.9 metres above the median plane where the beam is focused by two upstream lenses.

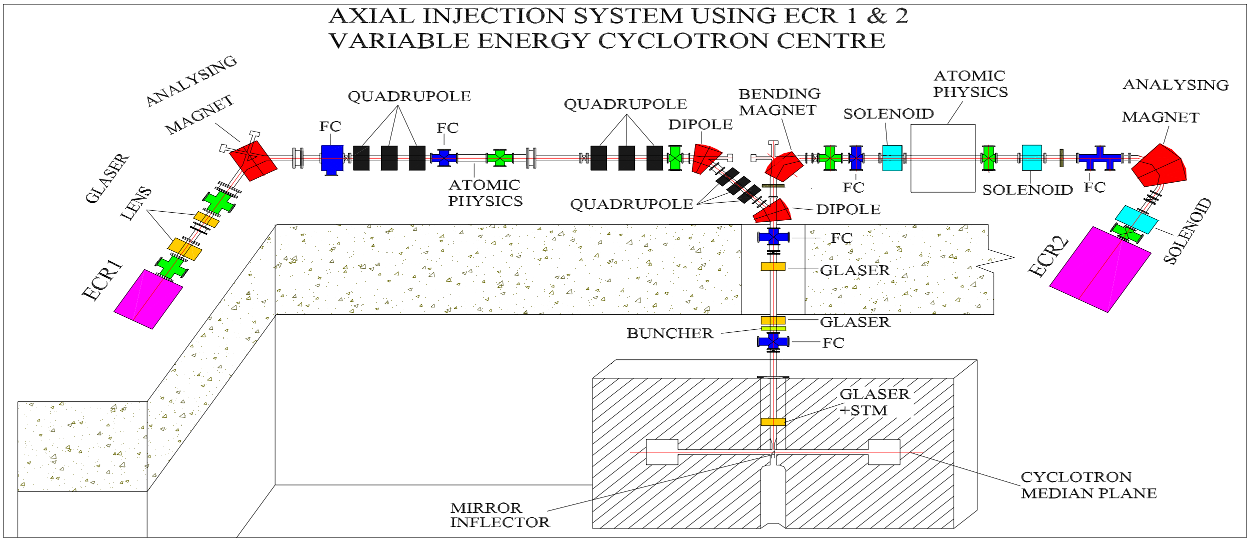

Figure 2.

4.2 *Inflector*

The beam after passing through the axial hole reaches the mirror inflector, which bends it in the median plane. The mirror inflector has gridded mesh of 50 micron tungsten wire with a spacing of 1.5 mm in the central zone. The inflector initially presented with lot of difficulties when it was put inside the cyclotron as the discharge current in the presence of magnetic field used to increase after few days of operation. After several experimentation to detect the problem it was found that the inferior o-ring used for insulation and vacuum sealing malfunctioned increasing the pressure in the inflector. Suitable changes have been incorporated in the design. Though after few weeks of operation it needs cleaning because of flake formation inside the inflector due to vacuum oil migration.

The inflector angle of 46.3^0 has been chosen. Initially 8 kV injection voltage was used but with improved performance of the insulator in the ion source 10 kV injection can be achieved.

The central region simulation studies have been done using Relaxation and centre region codes for electric field generation and studying the beam behaviour.

5 ACCELERATION OF BEAMS

Initially O^{5+} was used as the test beam for diagnosing problems of acceleration in the cyclotron. First external beams were obtained in mid-98 and beams were delivered to the users for experiments and beam characterisation. Time structure of 3.1 nsec were measured for 6 MHz operation.

The injection of beams is done in non scaling mode (always injected at the highest voltage feasible) to take advantage of overall better acceptance in the centre region. Simulation studies have shown that the emittance growth at the centre could be as high as 2 to 3 times due to coupling of motions in the axial hole-mirror inflector combination.

At present external beam of 300 enA of oxygen has been obtained corresponding to 1% of the analysed beam. The extraction efficiency for the cyclotron has been 25%.While 80% of the beam has been transported to the inflector only 10-15% survives to 6 inches indicating large loss. Even tuning of the injection line is crucial and systematics is still being studied. Neon and O^{6+} has been tuned. With the addition of ECR 2 more beams will be tuned depending on experimentalists' requirements.

To improve the injection efficiency the injection voltage and the accelerating voltage is being increased to 10 kV and 50 kV respectively. A 6-finger probe has been added to the target probe to better tune and optimise the centre region parameters. Several other modifications are being carried out in different subsystems related to handling irregularities in input power and upgrading subsystems.

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