HEAVY ION ACCEERATION USING 224 CM CYCLOTRON AT KOLKATA

C. Mallik,G. Pal, P.Y. Nabhiraj, S. Bhattacharya. G. S. Taki, S. Som, D.L. Bandyopadhyaya, S. Saha, K. Kundu, A.S Banerjee, C. V. S. Rao, B. Mukhopadhyaya, D.P. Hazra, K.G. Biswas, S.K. Mitra, M. Dutta, P.S. Chakraborty, A. Polley, R.C. Yadav, S. Chattopadhyaya, B. Soor, S. Pattanayak, J.S. Prasad, S.Dasgupta, Manoranjan Das, Sarabjit Pal, S.K.Das.,T.K.Dey, R. Dey, N.K. Mukhopadhyaya, R.K. Bhandari, B. Sinha
Variable Energy Cyclotron Centre,
I/AF,Bidhan Nagar, Kolkata 700064,India

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 first heavy ion beams were delivered. In 2002 the second ECR was connected to the cyclotron along with the associated injection line Now more new 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. In very near future the cyclotron will be used as primary source for Radioactive Ion Beam Facility.

INTRODUCTION

The 224 cm cyclotron at Kolkata 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. To achieve Heavy Ion beams indigenous development of Electron Cyclotron Resonance Ion source was taken up. After a number of improvements in the source design the currents obtained gave us the confidence to inject into the cyclotron. Since last few years Heavy Ion acceleration Programme is actively pursued.

MODIFICATIONS

Centre Region

The centre region modifications was 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.

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.

RF System

The old synthesized signal generator, used as rf signal source, has been replaced by a new one (Model: Agilent#8648A) with less than ±0.01ppm temperature stability of its internal reference oscillator. The existing driver amplifier, i.e., 1 kW Power Distributed amplifier using 8 nos. of water-cooled Eimac 4CW2000A tetrodes), is running continuously for the last 20 years and now it is being replaced by 2 nos. of 500W solid-state rf amplifiers (Model: Amplifier Research#500A100A) combined with a high power (2kW) 2-way in-phase rf combiner (Model: Werlatone#D6283) to drive the final high power (250kW output) rf amplifier based on water-cooled Burle 4648 tetrode. A PC-based Data-Acquisition system has been developed using a multi-function DAQ card (Model: NI#NI-PCI-6031E) to monitor all rf parameters and will be installed in the control room soon during the next shut-down period of cyclotron.

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. Due to surface damage of the spark plates they often need replacement.

Vacuum

The vacuum system mainly consists of two 38” diffusion pumps with chevron baffles cooled to -40 $^{\circ}$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 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 in the resonator tank is $1.2x10^{-6}$ torr. The pressure in the external beam lines have been improved to 5.10^{-6} torr.

Main Vacuum system had to be shut down twice to repair RF panel cooling tube last year. This problem has occurred several times and basically is due to brazing failure. It needs to be tackled by fabricating a new panel.

A pair of cryopanels has been fabricated and is ready to be installed in the Dee chamber. A trial run will be made to cool it to 80 K and measure its effective pumping speed for water vapour. Water vapour presently constitutes eighty percent of the total gas load. It is estimated that with the cryopanels operating at 80 K, pressure in the acceleration chamber would improve.

A programme has been initiated for computerised operation of the vacuum system. A few modifications in the Design of the control panel and operational logic are being worked out.

ION SOURCES

6.4 GHz ECR Ion Source

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.

14 GHz ECR Ion Source

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. 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. Table 1 shows the performance obtained with this source.

Table 1. Charge state distribution in ECR 2.

CS	O	Mg	S	Ar	Xe	Ta	Pb
6	510	58	42				
7	110	40	71				
8	21	50		560			
9		20	100	362			
10			77				
11				176			
12				100			
13				41			
14				18			
20					47		
21					46		
22					50		
23					51		
25					53	34	13
26					47	36	
27					25	24	19
28					13	17	12
29					7	11	18
30					2		15
31					1	4	11
32						2	7
33							4
36							1.2

INJECTION

Axial Injection Line

The beam from ECR1 is transported to the vertical section using glaser lenses, dipoles and quadrupoles. The beam is bent by two 45° dipoles having three quadrupoles of unity magnification.

The beam from ECR2 is focused at the common point located at image point of 45° section. The new injection line for ECR2 has already been installed. It consists of a 90° charge analysing magnet followed by solenoidal transport section and another 90° 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 . 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.1.

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 Glaser lenses. The beam roughly improves by four times when buncher is switched on.

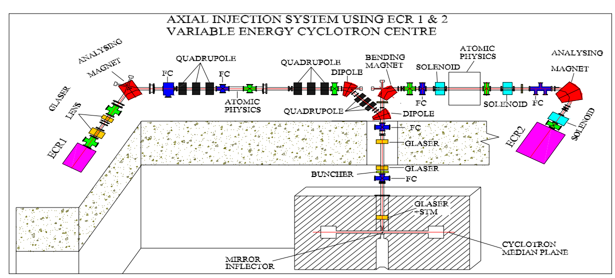

Fig. 1: Injection line layout for ECRIS-1 and ECRIS-2.

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. Suitable changes have been incorporated in the design. Though after few weeks of operation it needs cleaning because of Insulator damage or flake formation inside the inflector possibly due to vacuum oil migration.

The inflector angle of 46.3° 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.

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.

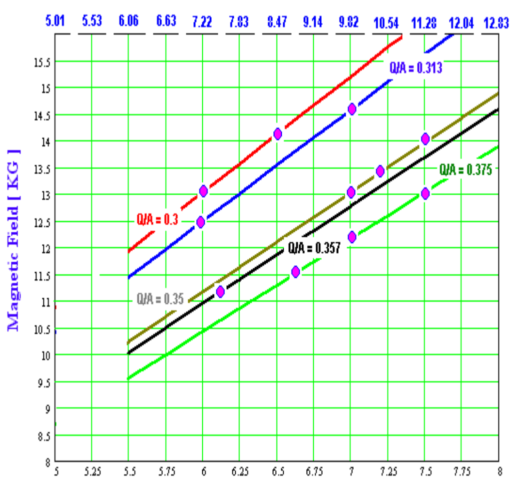

Fig. 2 Operating diagram where dots represent the beams developed

At present external beam of 1000 enA of oxygen has been obtained corresponding to 1.5% 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 systematic is still being studied. Neon and O^{6+} has been tuned. With the addition of ECR 2 more beams like Argon, Sulphur have been made available depending on experimentalists' requirements.

Several other modifications are being carried out in different subsystems related to handling irregularities in input power and upgrading subsystems.

Table 2: Accelerated Ion Species

Ion Species	Q	E (MeV)	Extractd Current (enA)
N^{14}	5+	105	070
O^{16}	5+	160	300
O^{16}	6+	140	1000
O^{16}	6+	160	530
O^{16}	6+	180	410
Ne^{20}	6+	170	200
Ne^{20}	7+	200	310
Ne^{20}	7+	210	260
Ne^{20}	7+	225	005
S^{32}	10+	230	060
Ar^{40}	12+	288	060

MODERNISATION OF SUBSYSTEMS

Since the cyclotron is now more than 25 tears old a number of subsystems need to be upgraded. Presently funding has been provided to upgrade the subsystems and is being actively pursued. A major activity would be to change the power supplies and automate different subsystems

1. In order to stabilize the magnetic field it has been decided to replace the existing trim coil power supplies and Main Magnet Power Supply by highly stabilized power supplies (30 ppm stability, 8 hours) and computer coil power supplies.There have been inhouse efforts to fabricate highly stable power supplies some of them have been installed in the cyclotron.

2. Low Conductivity water cooling system with a capacity of 300 cubic metre/hr for cooling of different components are being upgraded. Electropneumatic isolation valves for subheaders are being installed for sensing of water leaks.

3.An optical encoder based assignable knob is developed in-house to ease the adjustment of the set point of trim-coil power supply and beam line power supply by the operator during the beam tuning. A PS can be assigned from the GUI monitoring the status of all PS by touching that specific object on the touch-screen monitor. These efforts are being made to automate the present cyclotron to the extent possible.

EXTERNAL BEAM LINES

The external beam lines presently deliver beams to three channels where irradiation, charged particle spectroscopy and Gamma spectroscopy are carried out. The line as shown in the diagram have been modified to obtain better vacuum. The High Resolution Line which used a 160 deg magnet will now be used in achromatic mode to transfer the beam to Radioactive Ion Beam Facility. The beams will be delivered to this facility during the later part of this year. Beam lines are proposed in High Resolution Cave I for target stations.