OPERATION OF THE LBL ECR SOURCE INJECTION SYSTEM *

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Summary

The injection system for the LBL 88-Inch Cyclotron ECR source has been in operation since October 1984. It consists of 7 meters of horizontal beam line following the ECR source analyzing magnet, and 4 meters of vertical beam line down the axis of the cyclotron. Beams throughout the cyclotron energy range of 1-32 Mev/u, and particles from protons to xenon have been injected and accelerated in the cyclotron on 1st, 3rd, 5th and 7th harmonic modes. A non-scaling mode of operation is used in which a source voltage of about 10 kv is used for all beams. The overall transmission from source analyzing magnet to cyclotron external beam is typically 10%. The reliability and stability of the system has been excellent.

The Injection Line

The ECR source is described in another paper[1] in this Conference. The injection system was described previously in other Conferences[2,3,4]. The horizontal injection line is shown in Fig. 1. A photograph is shown in Fig. 2. For beam diagnostics four-jaw collimators placed along the beam line where the beam is large give diagnostic information on beam position. Steering is done with coils on the beam pipe or in the lenses. The vacuum pumping is done by turbo and cryo-pumps giving an operating pressure of 10^{-7} torr or lower in the beam line. The ECR source beam is focused by the first Glaser lens (magnetic solenoid with iron return yoke) through the first slit on to the first Faraday cup. The beam is then analyzed and refocused by the 90 degree magnet through a second slit onto a 2nd Faraday cup. A resolution of about 1/100 in mass is obtained with 0.8 cm wide slits. Since the energy spread of the ECR beam is less than 1/1000, the dispersion contribution to the beam size is negligible. Just after the first quadrupole doublet there is a scanning Faraday cup which can scan across the beam with the quadrupole off. The emittance of the central core of the beam ranges from 20-110 π mm mrad at 10 kV, un-normalized, going from high to low charge states. The energy spread of the central core is .1-5 eV for high to low charge states.

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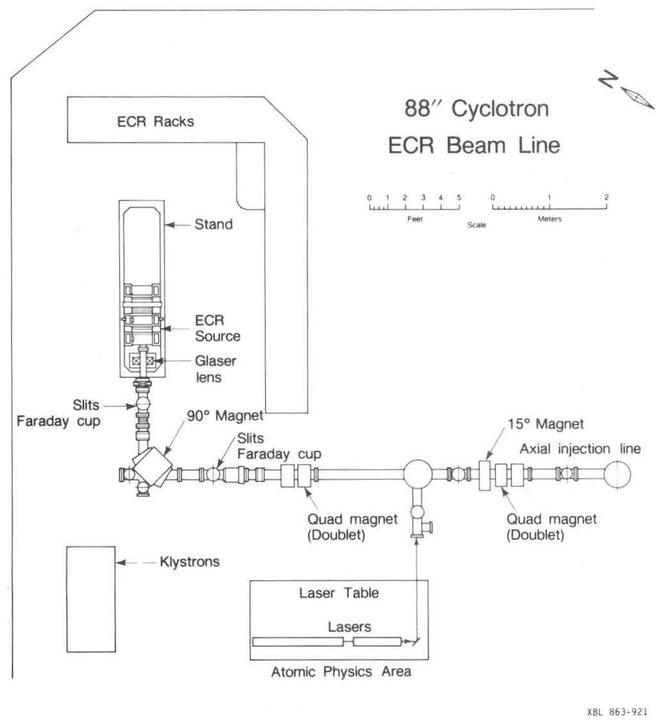

Fig. 1. ECR Source and horizontal section of injection line.

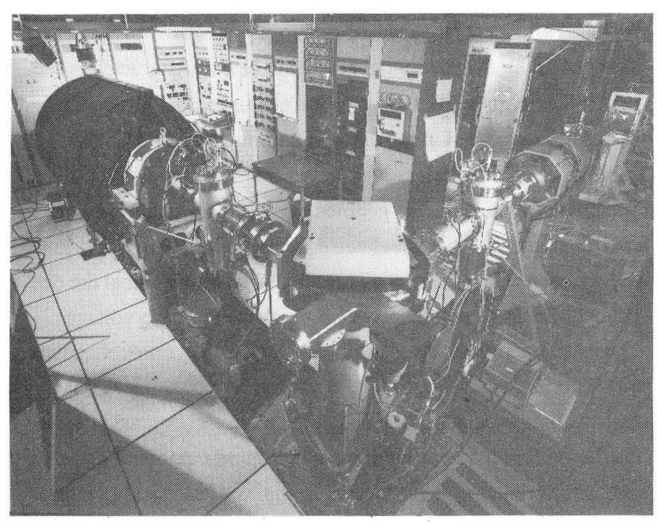

Fig. 2. Horizontal beam line with ECR Source on left and 90 degree analyzing magnet in foreground.

The beam is then transported by two magnetic quadrupole doublets to the 15 degree and 75 degree magnets which bend it into the vertical line, shown in Fig. 3. The polarized ion source is mounted vertically above the axial injection line and is used to inject polarized protons and deuterons. In the vertical line the focusing elements are 3 Glaser lenses. One of the upper Glaser lenses is shown disassembled in Fig. 4. The lower Glaser lens is shown being assembled in Fig. 5. The beam enters the cyclotron magnetic field at the bottom of the hole. This field produces a strong focusing effect on the beam[2].

A gridded buncher is placed near the bottom of the vertical line. It consists of an electrode driven at cyclotron rf frequency with a typical voltage of several hundred volts. The grids are placed on the entrance and exit of the electrode and on the ground electrodes facing the entrance and exit. The wires are .0025 cm diameter tungsten at .7 cm spacing. Fig. 6 shows the relation between the buncher voltage, V_B, the beam injection voltage, V_i, the particle charge state, Q, the cyclotron harmonic number, H, and the cyclotron beam energy, E_C. The beam travels about half an rf cycle in the electrode, so the effective length of the electrode, L_B, is about 1/2 $\beta\lambda$, where β is v/c and λ is rf wavelength. The system covers a broad cyclotron energy range as shown by the E_C/u scales set in the upper part of Fig. 6 for ions with charge/mass Q/A = .5 and .25.

The Center Region

At the median plane the beam is bent through 90 degrees by a gridded electrostatic mirror, shown in Fig. 7. The voltage on the mirror is typically .7 times the beam voltage. The wires are .005 cm diameter tungsten at .1 cm spacing. So the transmission of the beam in and out of the grid is 90%. The wires are wound on a frame which can be easily replaced. It is replaced after several weeks of running, since the wires are slowly sputtered away by the heavy ion beam. After leaving the mirror the beam enters the cyclotron center region, shown in Fig. 8. Inserts are placed in the dee and dummy dee to form narrow gaps for efficient acceleration. In our non-scaling mode of operation the orbits in this geometry do not have to have a constant pattern. This is indicated in Fig. 8 with a high and low energy beam. The requirement for beam centering is that the dee voltage should be approximately 5 times the injection voltage. The usual operating values are 10 kV for the injection voltage and 50 kV for the dee voltage. The advantage of operating in this non-scaling mode is that the dee voltage can be operated near its maximum for all beams, giving the minimum number of particle turns, high center region acceptance and low beam loss due to stripping during acceleration. Also, keeping the injection voltage high reduces the emittance in the transport line and gives higher transmission. The electric potential in the center region was calculated with the RELAX-3D program from the TRIUMF Cyclotron group. The central orbits were then calculated both in the median plane and with axial motion with the TRIWHEEL program from TRIUMF.

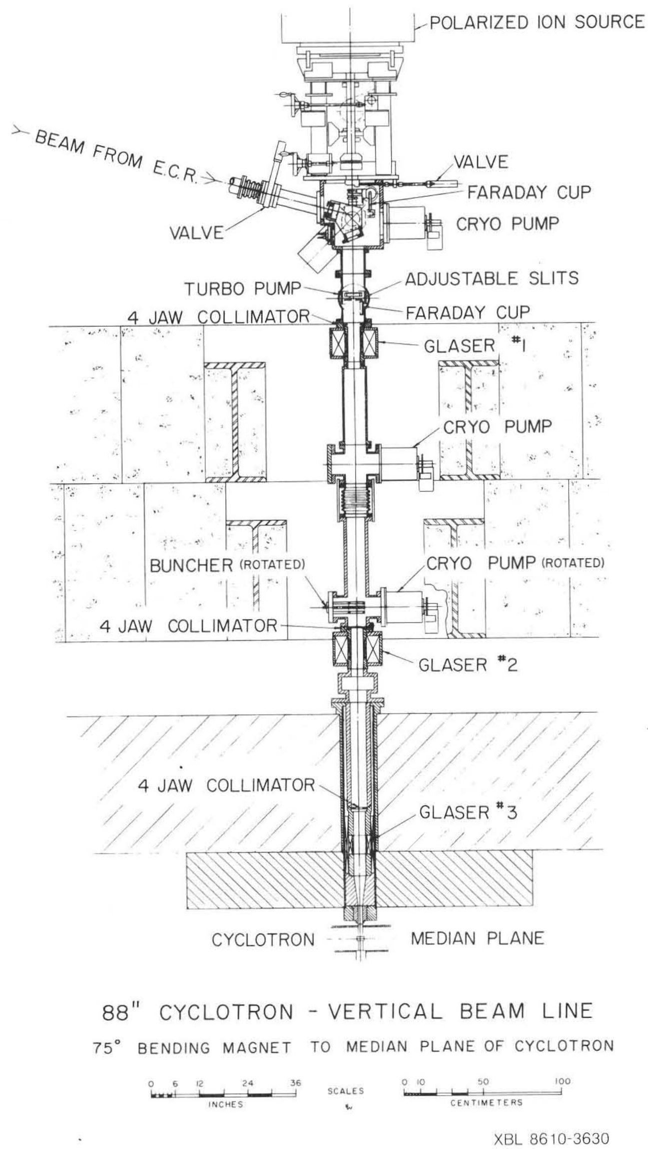

Fig. 3. Vertical section of injection line.

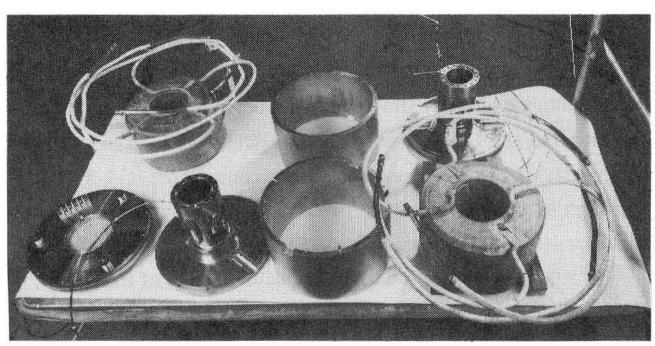

Fig. 4. One of two upper Glaser lenses of vertical line, disassembled.

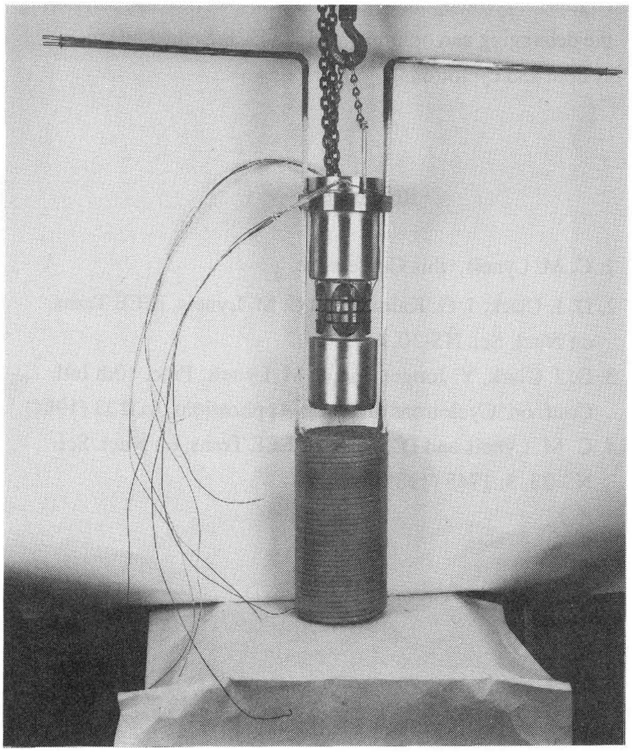

Fig. 5. Lower Glaser lens of vertical line during assembly.

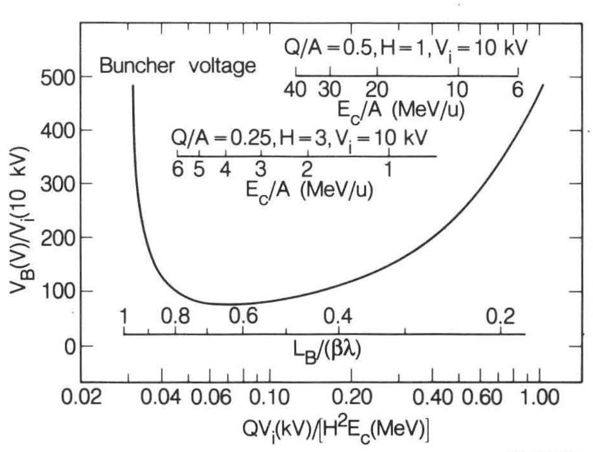

Fig. 6. Buncher voltage as a function of cyclotron parameters.

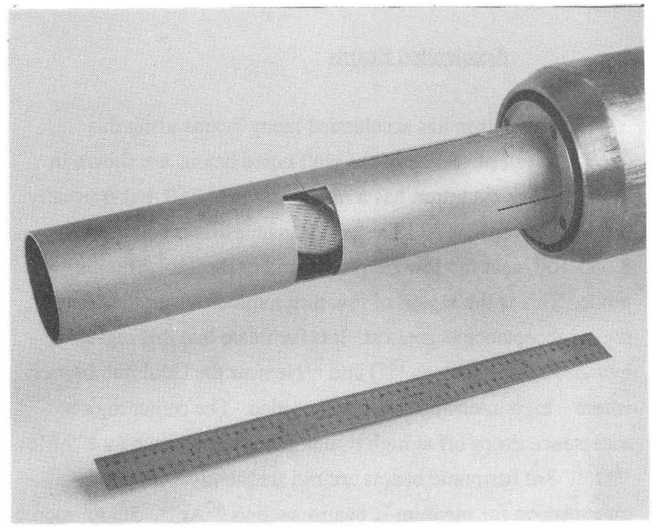

Fig. 7. Electrostatic gridded mirror in housing.

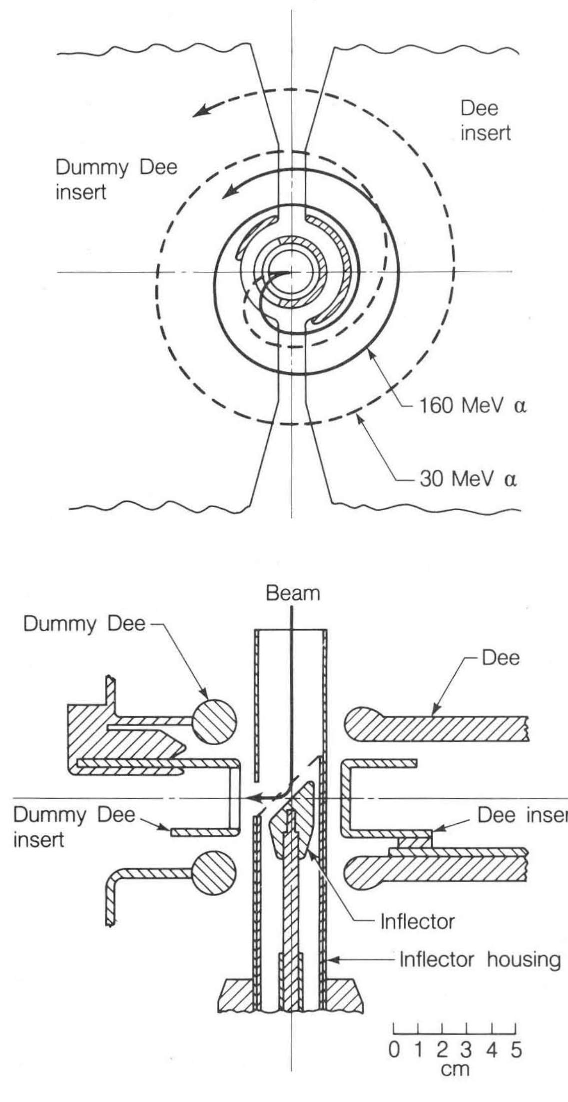

Fig. 8. Central region of cyclotron in plan and elevation views.

Accelerated Beams

The cyclotron has accelerated many beams using this injection system. Some of the well tuned beams are shown in Table 1. The cyclotron has a maximum K of 160, but is usually not run at over K=140. The best transmission is found for K=80-100, near the low frequency end of the 1st harmonic mode. This is the region of low turn number where the center region acceptance is greatest. It is fortunate that this region includes beams such as ^{18}O and ^{22}Ne near the Coulomb barrier, where high intensities are often needed. The center region acceptance drops off at high turn number beams such as 429 Mev $^{16}O^{7+}$. 3rd harmonic beams are run frequently with good transmission for medium K beams such as $^{40}Ar^{9+}$. 5th harmonic has been tested, but the center region acceptance drops much below that of 3rd harmonic. 7th harmonic has also been tested and showed a further large drop in transmission. The 5th and 7th harmonic beams have not been requested for runs because of their very low energy, and would require a center region modification to run efficiently. A study of the parameter settings for the injection line and cyclotron center region has been used to generate predicted parameter settings. For new beams these settings normally produce beam quickly on the internal cyclotron probe and then on the external Faraday cups. The parameters are then tuned for maximum transmission. The reliability and stability of the system has been excellent.

Table 1. Some Optimized Beams

Ion	Cyclotron Energy (Mev)	Harm.	Source Current (eμA)	Cyclotron External Current (eμA)	Trans-mission (%)
$^{14}N^{5+}$	180	1	60	7	11
$^{16}O^{2+}$	20	3	69	2	3
$^{16}O^{2+}$	20	5	67	.15	.2
$^{18}O^{5+}$	117	1	60	10	17
$^{16}O^{6+}$	315	1	40	3	7
$^{16}O^{7+}$	429	1	10	.2	2
$^{22}Ne^{6+}$	151	1	40	7	17
$^{24}Mg^{7+}$	192	1	20	1.5	7
$^{28}Si^{6+}$	180	1	60	3	5
$^{40}Ar^{9+}$	180	3	30	3	10
$^{40}Ar^{12+}$	504	1	6	.2	3
$^{86}Kr^{14+}$	301	3	2.5	.08	3
$^{129}Xe^{21+}$	451	3	.8	.02	3

Acknowledgements

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References

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