Low energy light ion beam development and Status of Variable Energy Cyclotron at Kolkata

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Introduction

The Variable Energy Cyclotron (K-130) is presently accelerating alpha and proton beams using an internal PIG ion source. This cyclotron is presently being used as primary source of beams (alpha and proton) for the production of radioactive atoms and also for doing nuclear physics experiments, radiochemistry and radiation damage studies etc. There was a demand from the experimentalists of very low energy light ion beam for performing sub-coulomb fission experiments. Earlier low energy He^{2+} (alpha) beam was developed from 5.5 MeV to 7.22 MeV. These beams were developed in third harmonic mode of operation. Present demand of beam energy is from 1 to 4 MeV**.** Hence a program was undertaken to develop of very low energy He^{+} and He^{++} beam by third and fifth harmonic mode of operation. Here to mention that fifth harmonic operation has been performed for the first time.

Extension of lower energy limit

The radio-frequency of alternating electric field of VEC range from 5.5 MHz to 16.5 MHz which corresponds 25 MeV to 130 MeV alpha (Fundamental mode). The resonator is so designed that it cannot set a frequency which is less than 5.5 MHz. Hence for acceleration of alpha particle of beam energy less than 25 MeV and proton of beam energy less than 6 MeV higher harmonic mode of cyclotron operation is performed.

Acceleration in Harmonic mode

For acceleration of particles at higher harmonic mode h, the particle revolution frequency ω_p (governed by magnetic field) and the frequency of the accelerating electric field ω_{rf} are set to satisfy the following relation [1]

$$\omega_{rf} = h\,\omega_p = h\,(qB/m)$$

In VEC cyclotron, acceleration is possible in odd harmonics, i.e. if h=1, 3, 5 etc.

In harmonic mode (for alpha and proton) for very low energy the required magnetic field is very low, compared to fundamental mode of operation and not suitable for stable RF operation.

In case of He^{+} beam, the scope of fundamental mode of operation is only at around 6.0 MHz with a very high magnetic field because of q/m =0.25. But at 6.0 MHz, the magnetic field required for third harmonic operation is suitable for stable RF operation. Even for fifth harmonic operation the required magnetic field is suitable for stable RF operation.

Beam development in third harmonic mode for He^{+} beam has been performed and obtained about 1.0 μA beam at first faraday cup (FC01) in the beam line. Beam energy was 3.33 MeV.

Fifth harmonic operation of He^{+} beam has also been performed and obtained about 100 nA beam at first faraday cup (FC01) in the beam line. Beam energy was 1.2 MeV.

Internal beam profile of He^{+} ion of third and fifth harmonics is shown in Figure 1.

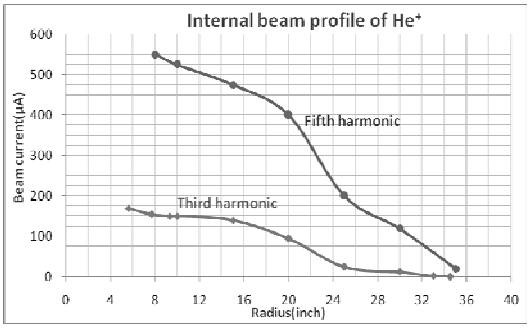


Fig.1 Internal beam profile of He^{+}

Table-1 and Table-2 shows some of the important operational parameters of low energy He^{+} and He^{++} beams.

Table: 1

Ion	He^{+} 3rd Harmonic	He^{+} 5th Harmonic
Frequency	6.0062 MHz	6.0062 MHz
Energy	3.33 MeV	1.2 MeV
Magnet	471.7 Amp	277.9 Amp
Ext. Beam	1000 enA	100 enA

Table: 2

Ion	He^{++} 3rd Harmonic	He^{++} 3rd Harmonic
Frequency	6.0062 MHz	9.00 MHz
Energy	3.33 MeV	7.22 MeV
Magnet	230.2 Amp	350.0 Amp
Ext. Beam	50 enA	50 enA

In harmonic operation beam current is generally much less compare to fundamental mode of operation. This happens because particle revolution frequency has to match precisely with RF. For this, isochronous field shape has to be very accurate. Beam profile along the radius up to the extraction radius was not up to satisfaction and effort is being made to improve the profile.
Acceleration of beams in higher harmonics of the RF, bring down the lower energy limit of the cyclotron.

Status of VEC

The Variable Energy Cyclotron has gone through huge upgradation activities which started in 2007. Modification of central region, upgradation of RF control system and vacuum control system, beam lines and the power supplies for the main magnet, trim coils, deflector and ion source has been modernized [2]. During shutdown, the major changes related to modification of various subsystems, relocating some of the existing systems or building modern operating facilities have been carried out.
The first experiment after upgradation activities started in February, 2010. Since then the cyclotron has been delivering proton and alpha beams of various energies and intensities for different types of experiments in four beam lines.

New vacuum chamber for the 159.5 degree analyzing magnet has been installed. The feeder beam line formerly known as high resolution beam line has been activated through which beam has been transported in achromatic mode to the rare-ion beam facility.

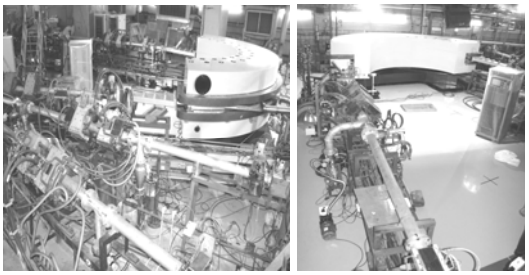
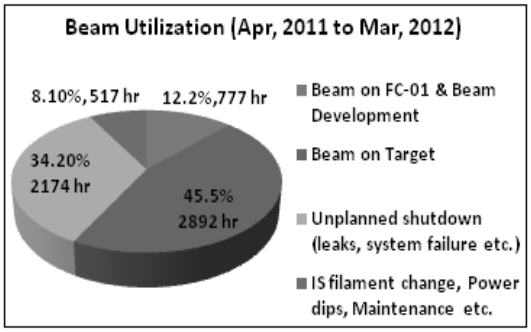


Fig.2 Analyzing magnet & beam lines of cyclotron and feeder line towards RIB facility

Beam utilization for the year 2011-12 is shown below in a pie chart.



At present the following ions with beam energy and current are available from K-130 cyclotron for performing experiments in four beam lines.

Ions	Energy (MeV)	Extracted Beam current
Alpha	30 - 65	20.0 μA
Proton	7.5 - 20	30.0 μA

The beam current stability on target has improved greatly after the upgradation and modernization activities. The reproducibility of the operational parameters is of great significance in the present operation practice.

References

[1] P.S. Chakraborty et.al, Proc. DAE symp. on Nucl. Phys, 50(2005).
[2] P.S. Chakraborty et.al, proceedings of InPAC, Feb 2011.