RF SYSTEMS OF THE VEC-RIB FACILITY*

H. K. Pandey#, A. Bandyopadhyay, A. Chakrabarti, S. Dechoudhury, D. P. Dutta, T. K. Mandi, V. Naik , Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata-700064, India
A.K. Basu, K. P. Ray, SAMEER, IIT Bombay, Powai campus, Mumbai-400076, India
A. Kumar, SAMEER Kolkata, Sector 5, Salt Lake, Kolkata-700091, India

Abstract

The VEC-RIB facility at present consists of a Radio Frequency Quadrupole linac (RFQ), three IH-Linac cavities and three re-bunchers. This paper describes the RF system and results of high power testing for above accelerator cavities.

INTRODUCTION

An ISOL type Rare Isotope Beam (RIB) facility is presently under development at VECC, Kolkata around the existing K=130 room temperature cyclotron [1, 2]. In first stage the low-energy (1.7 keV/u; q/A ≥ 1/14) RIB will be accelerated to about 415 keV/u using a RFQ (100 keV/u) and three IH-Linac cavities (187, 287, 415 keV/u respectively). The layout of RIB facility is shown in Figure 1.

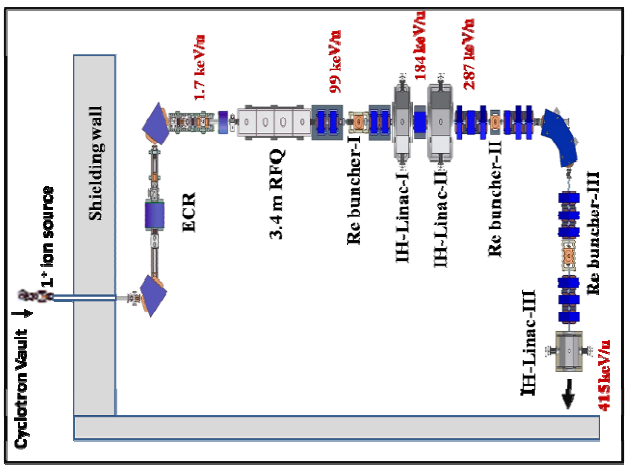

Figure 1: Layout of RIB facility.

The RFQ, first re-buncher and first two Linac cavities operate at the fundamental frequency of 37.8 MHz, while third Linac cavity and remaining re-bunchers are designed for the second harmonic at 75.6 MHz. The RFQ, the first re-buncher and first two cavities of the Linac have been installed and successfully operated in CW mode. The operating power ranges from 2 kW for the re-bunchers, up to 20 kW and 40 kW for Linac cavities and RFQ respectively. The third Linac cavity is installed and being tested at low rf power. Vacuum tube amplifiers are used for all the above cavities. The RF generators and low power control system for each accelerator cavity have been separately developed.

RFQ

The RFQ, first post accelerator of RIB facility, is already designed and commissioned [3, 4]. It accelerates q/A ≥ 1/14 beams with input energy 1.7 keV/u to 100 keV/u. It is 4-rod structure, 3.4 m long with characteristic radius of 7.1 mm, operating at 37.8 MHz in CW mode. An inter-vane voltage of 54 kV will be needed to achieve the final energy for a power loss of 35 kW. A photograph of the RFQ is shown in Figure 2.

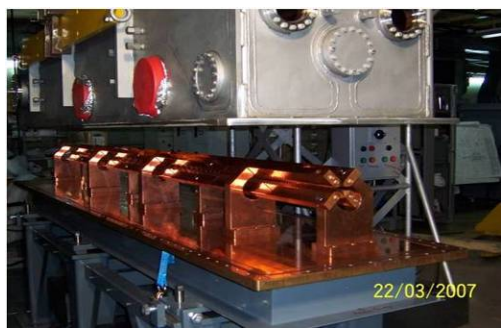

Figure 2: The 3.4m RFQ.

The RF structure measurements of the RFQ have been reported elsewhere [5]. Inter-vane voltage calibration has been done using power-loss measurement and X-ray end-point energy measurement. High power RF test has been done up to 18 kW in CW mode and measured inter-vane voltage was found to be about 37.0 kV. The data is consistent in both type of measurement. The X-ray spectrum corresponding to different RF power level of RFQ as measured in HPGe semi planar detector (*Type*: NGP 1000-15 of DSG, Germany) is shown in Figure 3. Maximum energy of the X-rays corresponds to the inter-vane voltage of the RFQ.

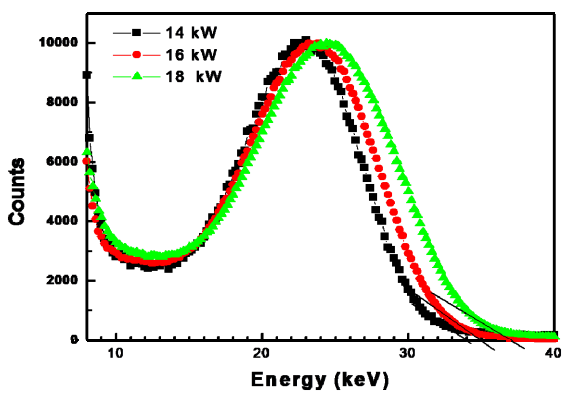

Figure 3: The x-ray spectrum measured for the RFQ.

* This is a VECC-DAE project
# hkpandey@veccal.ernet.in

Re-bunchers

The four-gap re-buncher located between the RFQ and the Linac-1 [6] is quarter-wave resonator terminated at one end and loaded by capacitive drift tubes at the open end (Figure 4a). The RF structure design and low power measurement has been reported elsewhere [7]. The re-buncher-I has been energised up to 1 kW CW RF power. Plot of pick-up voltage vs. RF power for Rebuncher-I is shown in Figure 4(b). Re-buncher-II and III are under development.

Figure 4: (a) Re-buncher I cavity (b) RF power vs. pickup voltage measurement plot for Re-buncher-I.

IH-Linacs

After initial acceleration in the RFQ, the subsequent acceleration of the beam will be done using three IH cavities to about 415 keV/u. A photograph of the third IH-Linac cavity is shown in Figure 5.

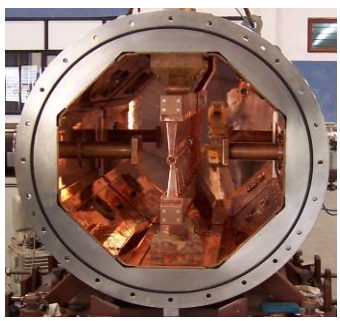

Figure 5: Third IH-Linac Cavity.

The detailed design and measurement results of IH cavities have been reported elsewhere [8].The first 2 IH cavities of 37.8 MHz have been designed and installed. The first IH- cavity is powered up to 14 kW and second up to 4 kW CW RF power. Figure 6 shows the variation of frequency with RF power for Linac-I.

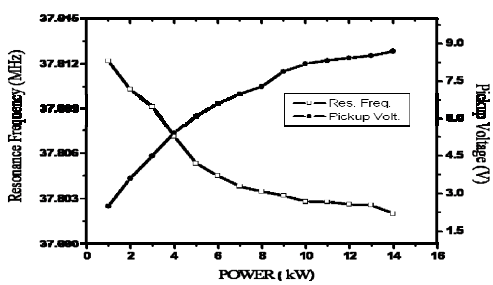

Figure 6: Frequency at high power for Linac-I.

RF SYSTEM

The rf transmitters have been designed and developed in collaboration with SAMEER Mumbai. The RF systems for RFQ, re-buncher-I, Linac-I and II are in operation, while the RF system for other two re-bunchers and Linac-III is under development. Figure 7 shows the RF distribution system for the facility. All cavities have been operated synchronously with closed-loop amplitude and phase regulation.

Table 1: Summary of RF Transmitters

RF system Parameters	RFQ Tx	Rebuncher-I Tx	IH Linac I & II, Tx
O/P Power	40 kW	2.0 kW	20 kW
f_o (MHz)	37.8 ±3.0	37.8 ±3.0	37.8 ±3.0
Driver Amp.	Triode 3CX5000A7 Tube	SSA (FET MRF 141G)	Triode 3CX5000A7 Tube
Final Amp.	Tetrode 4CW100000E Tube	Triode 3CX5000A7 Tube	Tetrode 4CW100000E Tube
Mode of operation	CW & Pulse	CW & Pulse	CW & Pulse
Trans. Line	3 1/8"	7/8"	3 1/8"
coupler	Loop type	Loop type	Loop type
VSWR	≤ 2.0	≤ 2.0	≤ 2.0
Harmonic	< -20dB	< -20dB	< -20dB
Phase Stab.	±0.5°	±0.5°	±0.5°
Level Stab.	± 0.5%	± 0.5%	± 0.5%

Inductive and capacitive tuners designed and developed indigenously [9] have been used for the RFQ and Linac & re-bunchers respectively. Water-cooled loop couplers with high vacuum window are used for coupling RF power to the cavities. Each RF cavity has two pick-up probes, one as a feedback for RF control system and other for cavity voltage measurement. The parameters of RF transmitter for different accelerator cavities are summarized in Table 1.

37.8 MHz RF Transmitters

The transmitters for RFQ, IH Linac-I and II consist of a two-stage vacuum tube amplifier [10]. A 3CX5000A7 triode tube based 2 kW power amplifier is used as a driver. Final amplifiers are equipped with a 4CW100000E tetrode tube. The RF transmitter for re-buncher is a single stage 3CX5000A7 triode tube amplifier. All transmitters have 100W solid state preamplifier. The photograph of 40 kW amplifier is shown in Figure 8.

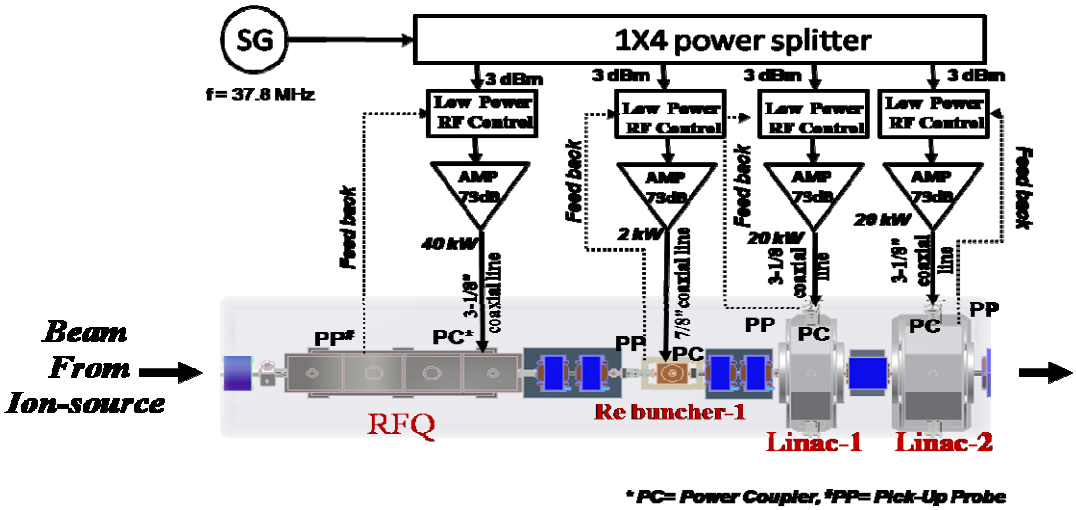

Figure 7: RF distribution system.

The RF power is fed from RF amplifiers through rigid and flexible coaxial lines.Mitra et al [11] has discussed about the criticality of length of the transmission line for stable operation of amplifier connected to high Q load. By varying the length of feeder line, an empirical proof of this phenomenon was obtained. We accordingly adjusted the length of feeder lines to the required value of multiple half wavelengths.

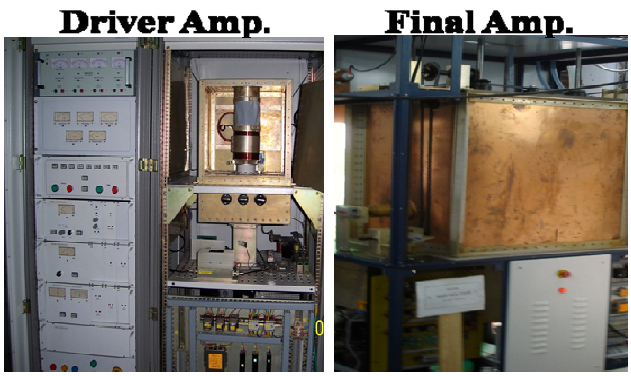

Figure 8: 40 kW amplifier for the RFQ.

RF control systems

The control system [12] of RF transmitter regulates amplitude and phase of accelerating voltage and also controls the tuners of the cavities, along with necessary interlocks and protection circuits.

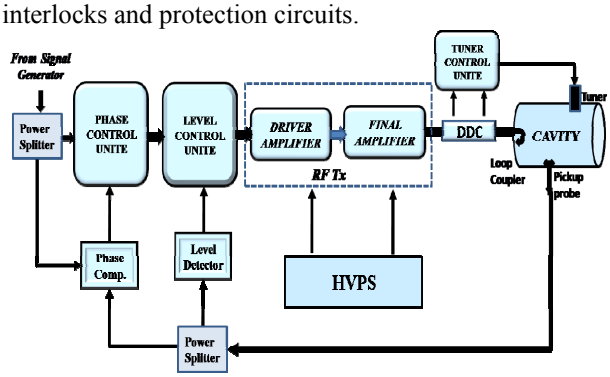

Figure 9: Block diagram of RF feedback control unit.

Block diagram of feedback control unit is shown in Figure 9. A low-cost ultra stable level and phase control circuit for each RF transmitter has been designed and tested. The amplitude stability of the level control circuit is ± 0.5%. The measured performance of the phase satiability is ±0.5° and phase control range is 360°.

SUMMARY

The four RF systems for the VEC RIB accelerators have been developed and commissioned. The high power RF test has been successfully performed to achieve the required gap voltage for O^{5+} for each accelerator cavity. The first beam test has been done for the unanalyzed beam of O^{5+} at the IH Linac-II exit. Further tests with other beams are planned. The development of other RF systems at 75.6 MHz is in progress.

REFERENCES

[1] A. Chakrabarti, Nucl. Inst. & Meth B 261, 2007, 1018.
[2] A. Bandhyopadhyay et al., Proc. PAC08, BC Canada.
[3] A. Chakrabarti et al., Rev. of Sci. Instr. 78, 2007, 043303.
[4] S. Dechoudhury et al, Rev. of Sci. Instr. 81(2010), 023301.
[5] H K Pandey et al, Proc. InPAC2009, RRCAT, India.
[6] S. Dechoudhury et al, Pramana J-Phys, 2010, in press.
[7] H.K. Pandey et al, Proc. InPAC2009, RRCAT, India.
[8] A. Bandhyopadhyay et al., Proc. LINAC08, Victoria, BC, Canada.
[9] H.K.Pandey et al, Proc. IEEE (AEMC-2007) Kolkata, ISBN: 978-1-4244-1864-0
[10] A K Basu, et al, Proc. InPAC2003, Indore, India. p455.
[11] A K Mitra, et. al. Proc. PAC95, Dallas Texas, USA, p1602.
[12] K P Ray, et.al, Proc. InPAC2005, Kolkata, India, p355.