RF TEST AND COMMISSIONING OF THE RADIO FREQUENCY STRUCTURES OF THE TRIUMF ISAC I FACILITY

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Abstract

A new linac has been built at TRIUMF to provide accelerated radioactive ions up to 1.5 MeV/u. The linear accelerator consists of sixteen rf systems, each working in cw mode. An 11.8 MHz multi-harmonic pre-buncher provides 86 nsec bunch spacing and is followed by an RFQ which is an eight meter long 4-rod, split-ring type structure operating at 35.4 MHz. A 106 MHz bunch rotator, a dual frequency chopper at 5.9 MHz and 11.8 MHz, and a 35.4 MHz spiral two-gap rebuncher constitute the rf structures for the medium energy beam transport section. This is followed by a variable energy 106 MHz drift tube linac (DTL) with five independent interdigital H-mode structures for acceleration, three split ring bunchers for longitudinal focusing and four magnetic triplets for transverse focusing. The bunchers were manufactured in INR, Moscow. In the high energy beam transport section, downstream from the DTL, a low beta 11.8 MHz buncher and a high beta 35.4 MHz spiral buncher have been installed. All the above rf systems have been tested, installed and commissioned and are now operating routinely. Tests and operational performances of these rf structures will be discussed.

1 INTRODUCTION

The first stage of a radioactive beam facility at TRIUMF, ISAC-1 [1], has been commissioned and a radioactive beam has been accelerated through the ISAC accelerator. The facility consists of a 500 MeV proton beam from the TRIUMF cyclotron, a thick target station, an on-line ion source, a mass separator, an accelerator complex and experimental areas. The accelerator chain is shown in Fig. 1. The accelerator consists of a 35.36 MHz RFQ which accelerates beams of $A/q \leq 30$ from 2 keV/u to 150 keV/u, a post stripper and a 106 MHz variable energy drift tube linac (DTL) to accelerate ions of $3 \leq A/q \leq 6$ to a final energy between 0.15 to 1.5 MeV/u. An 11.8 MHz multi harmonic pre-buncher is part of the low energy beam transport (LEBT) section. The 106 MHz bunch rotator used for time focussing, the dual frequency chopper for 85 ns and 170 ns pulse separation and the 35 MHz rebuncher for DTL matching are the rf structures which constitute the medium energy beam transport (MEBT). The high energy beam transport (HEBT) section consists of a low-β and a high-β bunchers which are required to maintain a good longitudinal emittance. All the rf structures have been commissioned in the accelerator [2,3] and have been fully tested for beam production. Basic parameters of the rf structures are listed in Table 1.

2 LEBT PRE-BUNCHER

The beam to be accelerated is pre-bunched at 11.78 MHz. The single gap pre-buncher cavity consists of two circular electrodes spaced 8 mm apart with a beam aperture radius of 7 mm.

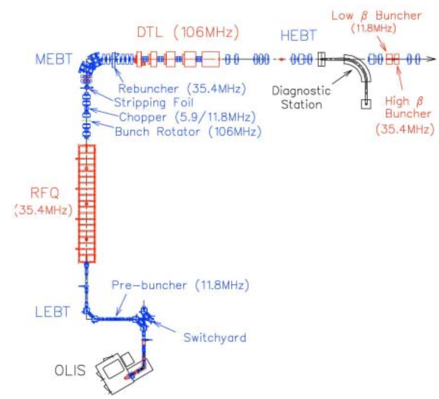

Figure 1: Layout of RF Cavities in ISAC-I

3 RFQ

The RFQ is a split ring 4-rod structure, 8m long with a bore radius of 7.4 mm operating at 35.36 MHz in cw mode [4]. The structure has a total of 19 split rings, each supporting 40 cm long modulated electrodes. A unique feature of the design is the constant synchronous phase of -25^{o}. The buncher and shaper sections of the RFQ have been eliminated, instead the pre-buncher as described in section 2, is used. The RFQ, shown in figure 2, was conditioned in pulse mode to gradually reduce the dark currents associated with field emissions.

4 BUNCH ROTATOR

The 106.08 MHz bunch rotator, developed and fabricated at INR RAS, Russia is designed to provide a time focus of the beam on the stripping foil. It is a three gap structure and is similar to the DTL buncher shown in figure 5.

5 DUAL FREQUENCY CHOPPER

The chopper is specified to have two modes of operation; one giving a bunch spacing of 85 ns and the other a bunch spacing of 170 ns [5]. The chopper system consists of two pairs of parallel plates, connected to two lumped circuit coils via feedthroughs, one pair driven at 11.8 MHz and the other at 5.9 MHz. The plates are dc biased to produce zero deflecting field at the base of the rf waveform.

Figure 2. The 35 MHZ RFQ

6 MEBT RE-BUNCHER

The 35.36 MHz two-gap re-buncher, positioned after the stripping foil is used for matching the beam into the DTL. It is a spiral structure made of solid copper and operates in cw mode [6]. The resonant frequency and Q of the final cavity were within 1% and 65% respectively of the values predicted by MAFIA 3D simulation. Figure 3 shows the re-buncher.

Figure 3. The 35 MHZ MEBT Spiral

7 DTL

The five independent inter-digital H-mode (IH) structures, each with 0 degree synchronous phase, provide the main acceleration. All the five IH tanks [7] are equipped with coarse tuners to bring the resonant frequencies of the tanks within the tuning range of the fine tuners. Bead pull measurements on all the cavities show the field variation of ± 1% across the gaps to be in close agreement with MAFIA simulations. However, measured Q and shunt impedance are lower than the values predicted by MAFIA and hence additional cooling was provided. Nominal power required for all the tanks are listed in Table 1. DTL Tank 2 is shown in Fig.4.

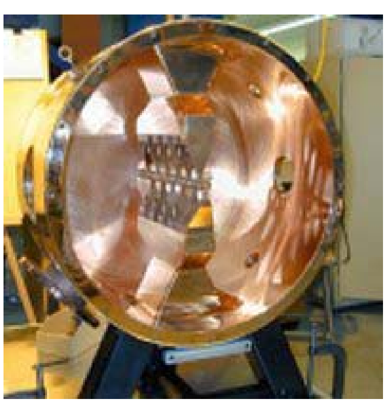

Figure 4. DTL tank 2

The bunchers for the DTL are three independent triple gap split ring resonators operating at 106.08 MHz. Buncher 1 is shown in Fig. 5. These are designed, developed and constructed at INR and fully tested at TRIUMF [8]. These three bunchers operate in cw mode at low β of 2.3%, 2.7% and 3.3 % respectively. All the bunchers showed stable operation at the rated power without any voltage breakdown.

Figure 5. The triple gap buncher

8 HEBT LOW BETA BUNCHER

To provide the initial bunching for beams from 0.15-0.4 MeV/u, a low-β (β_0=0.022) 11.78 MHz buncher is required. The resonant frequency of 11.78 MHz is obtained by an inductive coil, housed in an aluminum box, in parallel with the capacitance of the drift tube, located in a vacuum box. The rf feedthroughs which connect the coils with the drift tubes are designed to withstand 30 kV. A single coupling loop is employed to produce the required gap voltage. The buncher is shown in Fig. 6. The field distribution obtained from beadpull measurement agreed with MAFIA within ±1%.

Figure 6. The HEBT low beta buncher

9 HEBT HIGH BETA BUNCHER

A 35.36 MHz high-β buncher is a two-gap structure similar to the MEBT rebuncher. The operating mode is cw and provides bunching for beams from 0.4 to 1.5 MeV/u. This buncher along with the HEBT low beta buncher [9] is placed about 12 m downstream from DTL. The alignment of the drift tubes are within ± 1% of the drift tube diameter and the error between the axial electric fields in the two gaps is < 0.5%.

Table 1: RF parameters of 16 structures

RF Device	Structure	f MHz	Q	R/Q	V	P (KW)
Prebuncher	Plate + R	11, 23, 35	-	-	400 V	0.5
RFQ	Split Ring 4 Rod	35.36	8400	4.37	74 kV	80
Bunch Rotator	Split Ring	106.08	4500	1258	35.5 kV	3.5
Chopper	Coil + Plate	5.89	880	482	5.5 kV	0.045
Chopper	Coil + Plate	11.78	1065	264	7.4 kV	0.14
Rebuncher	Spiral	35.36	4000	1040	30 kV	1
DTL Tank1	IH	106.08	9000	12222	47 kV	3.9
Buncher 1	Split Ring	106.08	3950	1670	55 kV	8
DTL Tank2	IH	106.08	11260	18295	69 kV	10
Buncher 2	Split Ring	106.08	4880	1730	74 kV	10.2
DTL Tank3	IH	106.08	14350	24390	97 kV	16
Buncher 3	Split Ring	106.08	5700	1990	91 kV	11.6
DTL Tank4	IH	106.08	16250	21230	109 kV	19
DTL Tank5	IH	106.08	16600	19880	116 kV	20.3
Low Beta Buncher	Coil + Drift Tube	11.78	2150	4650	30 kV	1.5
High Beta Buncher	Spiral	35.36	6400	1430	170 kV	12.6
V is drift tube /electrode to electrode Voltage. Q and R/Q are measured.						

10 POWER AMPLIFIERS AND CONTROL

Table 1 summarizes the rf parameters of the 16 rf structures. Rigid and flexible coaxial lines are used to transmit power from the amplifiers to the rf structures. Solid state amplifiers are used for cavities requiring less than 2 kW power and tube amplifiers are used for higher powers. Most of the amplifiers have been designed and fabricated in-house. Commercial tubular ceramics have been used for the rf feedthroughs where electron beam welding, fabrication, assembly and test have been done at TRIUMF. Each rf structure is provided with two calibrated pick up probes, one for feedback control and the other for cavity voltage measurements. Also, each structure has it's own stepping motor driven fine frequency tuner, which is connected to it's dedicated controller. All the rf systems are phase locked via a frequency distribution unit. The rf structures run synchronously but at the same time they have individual close loop amplitude and phase regulation and automatic frequency tuning via the fine tuners [10].

11 CONCLUSIONS

The various rf structures were installed and beam tested in a progressive manner. The full 19 ring RFQ was tested in 1999 and prior to that an initial beam test was done in 1998 with the first 7 rings of the RFQ and the pre-buncher In the spring of 2000, the MEBT rebuncher, a part of the DTL comprised of Tank 1, the magnet triplet and the DTL buncher1 were completed. Subsequently, the remaining DTL tanks and the DTL bunchers were commissioned. On December 21, 2000, the first beam (4He1+) was accelerated through the ISAC DTL to full energy. In April 2001, the HEBT high beta and in May 2001, the dual frequency MEBT chopper were installed. On July 26, 2001 the first radioactive beam was accelerated through the ISAC accelerator to experiments. The HEBT low beta was commissioned in September 2001. The accelerator systems is routinely providing beam for experimenters.

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