RF SYSTEMS OF THE TRIUMF ISAC FACILITY

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Abstract

Five rf systems, each operating in cw mode, have so far been specified for the ISAC accelerator system; a pre-buncher, an RFQ, a MEBT re-buncher, five DTL cavities and three DTL bunchers. The pre-buncher was designed and built to operate at a frequency of 11.66 MHz plus three harmonics. So far it has operated successfully at full nominal voltage with fundamental plus the addition of two harmonics. Both the 8-meter long, 4-rod, split-ring type RFQ and the spiral two gap MEBT re-buncher were designed to operate at 35 MHz. The initial 2.8 meters of the RFQ (7 out of 19 rings) were installed in the 8 m long tank and have been successfully operated at full power with beam. Dark currents associated with field emission initially accounted for 40% extra power consumption at full voltage but could be eliminated with high power pulse conditioning. The remaining 12 rings are being installed to enable us to accelerate cw radioactive ion beams to 150 keV/u. A full scale model of the MEBT re-buncher was built and tested and the final structure is in the design stage. The DTL accelerator system consists of a series of multi-gap interdigital H-mode tanks and three gap split-ring buncher cavities both operating at 105 MHz. The first DTL cavity has been fabricated and is undergoing rf tests. The first DTL buncher was tested to twice the nominal operating power. All amplifiers for the above were designed and built in house. This paper will report on the performance achieved for these systems.

1 INTRODUCTION

A radioactive ion beam facility is being built at TRIUMF [1]. The accelerator complex of ISAC [2] consists of several different rf systems as shown in Fig. 1. Instead of a bunching section in the RFQ, the beam is pre-bunched at 11.66 MHz with a single gap, pseudo saw-tooth buncher. An 8 m long, 35 MHz, four vane split ring RFQ structure accelerates ions from 2 keV/u to 150 keV/u. The details of the bunch rotator and chopper have not been specified yet and will not be included in this paper. In the MEBT the beam is matched into the DTL with quadrupoles and a spiral two-gap 35 MHz re-buncher. The 105 MHz variable energy DTL post stripper [3] accelerates ions to a final energy between 0.15 MeV/u to 1.5 MeV/u.

2 LEBT PRE-BUNCHER

The pre-buncher [4] consists of two circular electrodes spaced 8 mm apart forming a single gap with a beam aperture of 7-mm in radius. The fundamental frequency of 11.66 MHz and the first three harmonics are individually phase and amplitude controlled, and combined at signal level. The signal is amplified by an 800 W broadband amplifier that drives the two plates in push-pull mode with a peak voltage of about 200 V (400 V between plates). The capacitive plates are externally loaded with a resistor to make the system broadband. The amplifier is a 2 stage, transformer coupled wide band solid state amplifier. Because of a reduced gain at the higher frequencies, the initial testing was done with only two harmonics. Optimization of amplitude and phase of each harmonic results in an almost saw-tooth modulation on the beam velocity. The Pre-buncher system operated very reliably at full power for the first beam tests with the RFQ [5].

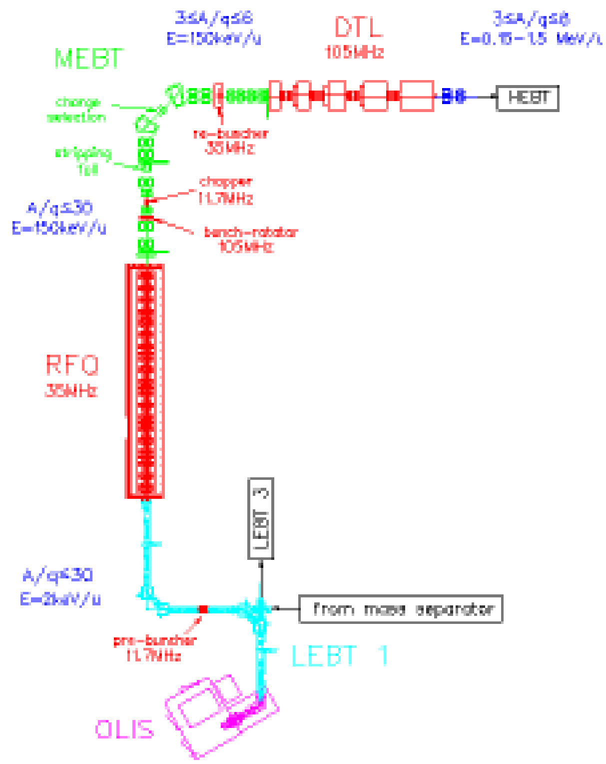

Figure 1. The ISAC Linear Accelerator

3 RFQ SYSTEM

The ISAC RFQ is an 8-meter long, 4-rod split-ring structure operating at 35 MHz in cw mode. An initial 2.8m section [6] of the accelerator (7 of 19 rings) was installed and aligned in the 8m, square cross-section, vacuum tank (Fig. 2) to allow RF and beam tests to be

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carried out. The stringent, +/- 0.08 mm, quadrature positioning tolerance of the four rod electrodes was achieved [7] and a relative field variation along the 2.8 meter of the RFQ was measured to be +/- 1%, using the standard bead pull method.

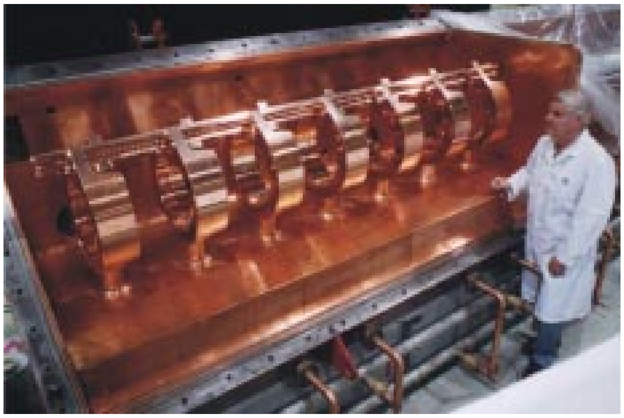
Figure 2. Seven ring assemblies installed and aligned ready for tests.

At signal level 57% of Q-value and a frequency within 2.8% of MAFIA simulations were achieved. Following a three day bake out at 60°C a base pressure of 1.4*10-7 torr was reached and 76 kV (2kV above design value) was achieved on the electrodes within four hours at the anticipated power level of 30 kW with an increase in pressure to 4.0 *10-7 torr. We were able to maintain this condition for two hours before our first major amplifier overload occurred. Subsequently, we were never able to achieve the above voltage for the same power. The rf power increased by as much as 40% for the same voltage level of 76 kV due to dark currents associated with field emission along the electrodes. The dark currents were essentially eliminated by one hour of high power pulse conditioning. The RFQ operated continuously for 15 hours at nominal voltage plus various runs for 5 and 10 hours before being interrupted by an amplifier trip. These amplifier trips were later found to be caused by a failing component in the grid bias power supply. Automatic recovery from a high VSWR has now been incorporated in the RF controls to cut the RF drive rather than trip the amplifier. Based on the RFQ prototype results, an amplifier was designed and built in house for a power output of 150kW. As a result of improved shunt impedance and reduced operating voltage, the 19 rings will only require 85 kW of RF power and the amplifier has been successfully tested into a resistive load to this power level.
The remaining 12 rings are now being installed and aligned to enable us to accelerate cw radioactive ion beams to 150 keV/u.

4 RF CONTROLS

The feedback control system for the ISAC pre-buncher regulates a 11 MHz signal and up to its third harmonic in both amplitude and phase to synthesis a special waveform for beam bunching. The RFQ control system uses a phase locked loop frequency source to generate a 35 MHz signal and also uses In-phase and Quadrature phase for amplitude and phase regulations. The system has a self-excited mode of operation that uses the RFQ cavity itself as the frequency-tuning element and allows the RFQ cavity to run without tuning control. The RFQ and the prebuncher, while operating at different harmonics, are phase locked together via a frequency distribution unit by generating these different harmonics with different phase shifts between them. The above control systems have been commissioned, enabling the prebuncher and the RFQ to operate coherently.

5 MEBT RE-BUNCHER

The MEBT rebuncher [8] will operate cw at 35 MHz with a gap voltage of 30 kV. Two designs for the 35 MHz rebuncher, a folded $\lambda/4$ and a spiral were evaluated on the basis of cost, size, rf and mechanical properties. A full-scale prototype of the spiral with water-cooling was constructed to measure the mechanical vibrations as well as rf parameters. The tests reveal that the vibrations are much lower than the allowable limits. MAFIA simulations have been done on the spiral to check the validity of the rf measurements of the prototype. From the computed and measured values of the shunt impedance, it is estimated that 1 kW of rf power will be adequate to produce a gap voltage of 100 kV.

6 DTL IH TANKS AND BUNCHERS

6.1 IH Tank

The first IH tank [9] with the stems and ridges installed and aligned are shown in Fig. 3. The ridges are mechanically fastened to the tank wall and therefore the fabrication tolerance on the flatness and surface finish of the bottom of the ridges and the mounting surfaces on the tank wall are very stringent in order to insure a good electrical contact.
The frequency was measured to be 3.5% higher and the Q to be 20% lower than the values from MAFIA simulations. A bead pull measurement shows the field variation across the gaps to be in close agreement with MAFIA simulations, causing only a +/- 0.1% phase error of the beam at the gap. Full power of 3.6 kW and drift tube gap voltage of 87.5 kV was achieved following 36 hours of low level multipacting conditioning. Stable operation for 100 hours was achieved.

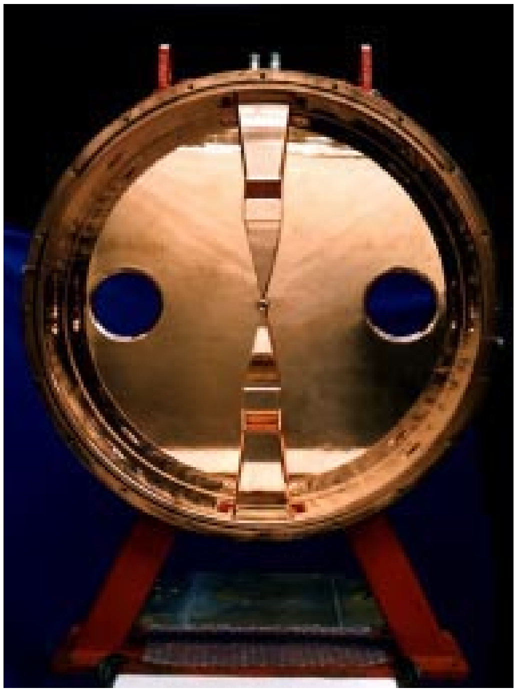

Figure 3. First DTL tank with ridges and stems installed and aligned.

6.2 Triple-Gap Bunchers

Shown in Fig. 4 is the first DTL buncher [10] that was developed at INR and tested at TRIUMF. It is a triple gap split ring rf structure operating at 105 MHz with 56 kV gap voltage. At signal level 74% of Q-value and frequency within 0.6% of MAFIA simulations were achieved.

Figure 4. First DTL Buncher developed and manufactured at INR, Russia.

With a cooling water flow of 20 l/min, the mechanical vibrations were measured to be in the order of 1 micron. The first of 9 RF power amplifiers for the DTL linac was completed and successfully tested into a resistive load at a power level of 22 kW. This amplifier was used to test the INR buncher to 16 kW (2X nominal power) with stable operation. The remaining power amplifiers for the DTL are in the process of being assembled. Movement of the drift tubes due to the rf thermal load of the ring was measured using a telescope on targets installed inside the drift tubes. With a cooling water flow of 17 l/min per arm of spiral, the centers of the drift tubes were displaced by 0.25 mm when full rf power was applied. By reversing the water flow to cool the hottest ring area first, the displacement was reduced to 0.125 mm.

7 CONCLUSION

The commissioning of the Pre-buncher, RFQ and associated rf control systems enabled us to reach our goal of accelerating beam from the first seven rings of the RFQ [11]. Our goal now is to accelerate beam from the full compliment of 19 RFQ rings by the end of the year. It is hoped that the MEBT Re-buncher will also be commissioned by the end of the year followed by the commissioning of the first DTL section in the spring of 2000.

8 REFERENCES

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