ISAC RF STRUCTURES AND COMMISSIONING

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Abstract
The ISAC accelerator for exotic ions employs an 8 m long 35.3 MHz cw RFQ to accelerate ions of A/q ≤ 30 from 2 keV/u at the RFQ entrance to 150 keV/u at the stripper/charge-selection location downstream. After stripping, a 5-tank-IH-DTL structure resonating at 106 MHz will accelerate ions to an energy variable between 0.15 and 1.5 MeV/u. Three split-ring bunchers and four magnetic quadrupole triplets are included in the DTL section for longitudinal and transverse focussing. Upstream of the RFQ an 11.8 MHz single-gap pseudo saw-tooth buncher replaces the adiabatic gentle buncher section in the RFQ. Downstream of the stripper a 35 MHz spiral re-buncher focuses the beam longitudinally at the DTL entrance. Pre-buncher, RFQ, re-buncher, first DTL cavity and first DTL buncher have already been installed and tested to full power with beam. The remaining DTL cavities and bunchers are in various stages of manufacturing and testing. The 1.5 MeV/u accelerator (ISAC 1) is scheduled for completion before the end of 2000.An extension to the accelerator (ISAC-II) has recently been funded to increase the final energy to at least 6.5 MeV/u for A≤ 150.

1 INTRODUCTION

The 500 MeV primary proton beam from the cyclotron has already been operated at 20 μA on target for experiments at ion source energies (≤60 keV). The proton beam intensity will soon be increased to 100 μA. The first phase of the accelerator, ISAC I [1], is almost complete . Exotic beams with A/q ≤ 30 and energy between 150 keV/u and 1.5 MeV/u are scheduled to be available by year-end. The pre-buncher, the RFQ, the MEBT including stripping foil, charge-selection section and re-buncher, the first section of the DTL structure including first DTL tank, magnetic triplet, and first split-ring buncher have already been installed, commissioned at full power and tested with beam. The layout of the ISAC linear accelerator is shown in Fig. 1.
Funding for the ISAC II extension [2] was recently approved. Design and prototyping are underway. Completion of the ISAC II accelerator which includes an IH DTL accelerating structure from 150 keV/u to 400 keV/u, a stripping charge-selection section at 400 keV/u, and a superconducting linac with a low β (71 MHz), medium β (106 MHz) and high β (141 MHz) sections between 400 keV/u and 6.5 MeV/u are planned over the next five to six years in a new experimental building addition.

2 LEBT PRE-BUNCHER

The pre-buncher [3] consists of two annular electrodes with an aperture of 7-mm radius spaced 8 mm apart.The fundamental frequency of 11.8 MHz and two additional harmonics are individually phase and amplitude controlled and combined at signal level. The effective voltage between plates is 400 volts. Optimization of amplitude and phase of each harmonic results in an almost saw-tooth modulation on the beam velocity.

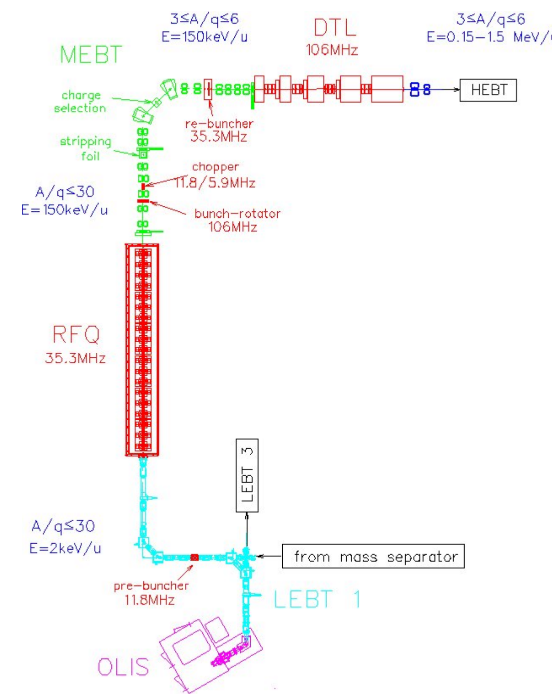

Figure 1. The ISAC Linear Accelerator.

3 BUNCH ROTATOR AND CHOPPERS

The bunch rotator, developed and fabricated at INR RAS, Russia, is very similar to the DTL buncher in Fig 5. The effective voltage is 60 kV at a power level of 3 kW.
In order to meet all the demands for chopping, a system of two sets of chopper plates at 5.9MHz and 11.8 MHz, capable of being dc biased, was adopted. This structure is in the early stages of prototyping.

4 RFQ SYSTEM

The ISAC RFQ is an 8-m long, 4-rod split-ring structure operating at 35.3 MHz in cw mode. The full complement of 19 rings shown in Fig. 2 has now been tested to full RF power with beam. In order to meet the stringent, +/- 0.08-mm quadrature positioning tolerance of the electrodes, the three-dimensional intersection alignment method [4] was used. The relative field variation along the RFQ was measured to be within +/- 1%. Signal level measurements gave a frequency of 35.4 MHz and a Q of 8700.

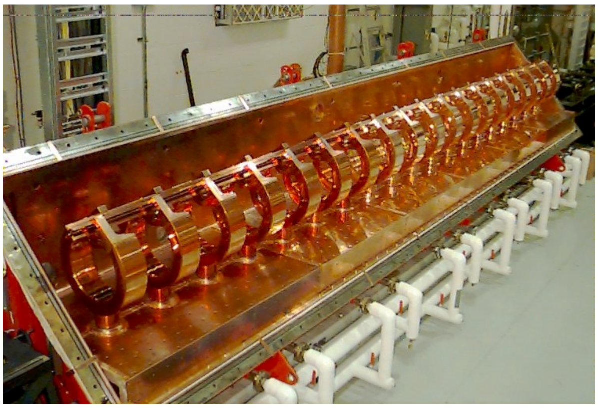

Figure 2. The RFQ 19 ring structure.

Careful cleaning and high power pulsing reduced the growth rate of dark currents associated with field emission by two to three orders of magnitude. Initially at the nominal voltage of 74 kV, the dark currents caused an increase of power from 75 kW to 100 kW in 2 hours. Now the power due to dark currents increases by only 5 kW and then levels off in 2 days. The amplifier is capable of 150 kW for peak power pulsing.

5 MEBT RE-BUNCHER

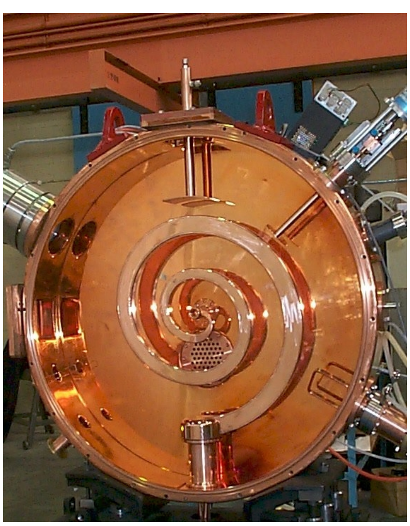

Figure 3. MEBT Spiral Re-buncher.

The spiral 35 MHz two-gap rebuncher structure [5] is NC machined from solid copper. Water pipes are soldered to the inner and outer surfaces of the spiral, which is housed in a 36" diameter tank. The open end supports the drift tube and has a stem support at the bottom as shown in Fig. 3. The resonant frequency (35.52 MHz) and Q (3700) of the cavity were within 1 % and 65 % of the value predicted by MAFIA 3D simulation respectively. A fine tuner with a tuning range of 80 kHz is employed to control operational frequency shifts.

The shunt impedance was measured to be 490 k-Ω. RF power of 1 kW cw was required to obtain the specified nominal tube voltage of 30 kV.

6 DTL IH TANKS AND BUNCHERS

Figure 4. First DTL tank with ridges and stems installed.

6.1 IH Tank

The variable energy DTL is based on five independent interdigital H-type structures operating at 106 MHz. The first IH tank [6] is shown in Fig. 4. Bead pull measurements show the field variation across gaps to be in close agreement with MAFIA, causing only a +/- 0.1% beam phase error. Stable full power operation at 3.6 kW and drift tube gap voltage of 87.5 kV were achieved following 36 hours of low level multipacting conditioning.

6.2 Triple-Gap Bunchers

The variable energy DTL requires three independent triple gap split ring resonators operating at 106 MHz. Shown in Fig. 5 is the first DTL buncher [7], developed and constructed at INR. The buncher operates at a gap voltage of 56 kV. At signal level the frequency was within 0.6% of MAFIA simulations and 74% of the MAFIA Q value of 4300.

The structure was tested to its full power of 8 kW and has been installed in the ISAC accelerator complex for beam tests. The remaining two bunchers operating at 78 kV and 94 kV gap voltage are presently being tested at TRIUMF.

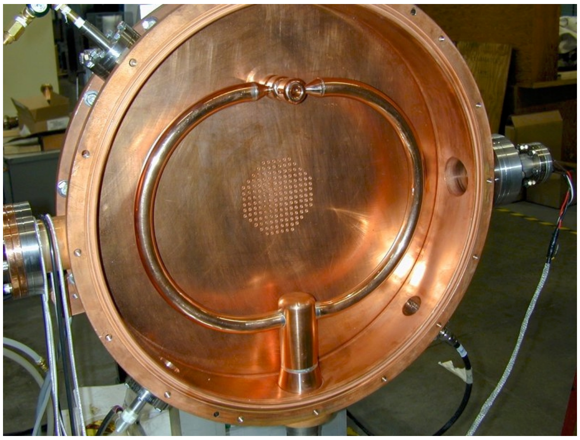

Figure 5. DTL Buncher developed and manufactured at INR, Russia.

7 RF CONTROLS

The RFQ control system uses a phase locked loop frequency source to generate a 35 MHz signal. All the rf systems use In-phase and Quadrature phase for amplitude and phase regulation. Although the different rf systems operate at different harmonics, they are phase locked together via a frequency distribution unit by generating these different harmonics with different phase shifts between them. Control systems have been commissioned to enable the pre-buncher, RFQ, MEBT rebuncher, DTL Tank#1 and DTL buncher to operate coherently with beam.

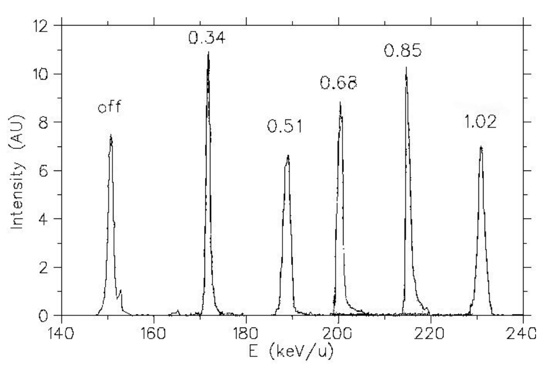

Figure 6. Final beam energy for various DTL tank1 amplitude settings.

8 BEAM TESTS

Beam tests have been done periodically as portions of the accelerator were installed. For the RFQ an initial beam test was done with the first 7-rings installed [8] in 98. The full 19-ring beam test was completed in 99. This spring a beam test on the MEBT rebuncher and the first section of the DTL, comprising Tank 1, magnet triplet and buncher 1, has been completed.

The following milestones have been achieved: (a) Pre-buncher with three harmonics optimized to allow the calculated 82% capture into the RFQ's phase acceptance; (b) RFQ tested over full voltage range with energy, energy spread, longitudinal acceptance and transverse acceptance measurements as predicted; (c) MEBT rebuncher, DTL tank1 and buncher1 tested with beam to demonstrate the full variability in beam energy with beam quality as predicted. The final beam energy spectrum for various DTL set-points, relative to full energy for the section, is shown in Fig. 6.

Final tests on the 1.5 MeV/u accelerator, including MEBT chopper, bunch rotator, DTL sections 2-5 and HEBT buncher rf power tests and corresponding beam tests, will commence in Nov. 2000.

9 SC CAVITY PROTOTYPE

The effort towards a superconducting heavy ion linac at TRIUMF for the ISAC-II project has entered a prototyping phase. In collaboration with INFN-LNL and Zanon in Italy we are fabricating a prototype cavity for the medium β (β_o=0.072c) 106 MHz section. The cavity is fabricated from bulk Niobium with a two-gap quarter-wave geometry and a design gradient specification of $E_a \geq$ 6 MV/m with 7 W of rf power at 4.2 °K.

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