RF AMPLIFIERS AND STRUCTURES FOR ISAC/TRIUMF

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Abstract

The ISAC-I accelerator is comprised of two room temperature linacs; a 35MHz RFQ and a 106MHz separated function drift tube linac producing an accelerating voltage up to 4.5MV and 8.1MV respectively. In addition a pre-buncher, chopper and several re-bunchers are used in the accelerator chain to manipulate the longitudinal phase space. A heavy ion superconducting linac is being installed at ISAC/TRIUMF to increase the energy of ISAC-I from 1.5 MeV/u to 6.5 MeV/u for ISAC-II. A first stage, now in commissioning, consists of twenty medium beta cavities driven by twenty, 106MHz, tube amplifiers. In the second stage of ISAC-II, 20 high beta quarter wave superconducting cavities will be installed operating at 141 MHz. A transfer line connecting ISAC-I and ISAC-II has a room temperature buncher cavity at 35 MHz. This report will summarize rf amplifiers employed in ISAC facility and discuss the choice of amplifiers for the second stage of ISAC-II. Some of the re-furbishing and improvements that are done to ISA-I rf system will also be discussed.

INTRODUCTION

A heavy ion superconducting linac with a total accelerating voltage of 20 MV is being installed as a first stage of the ISAC-II upgrade as an addition to the existing room temperature linac ISAC-I. ISAC–I has the capability of maximum energy of 1.8 MeV/u for ions with $A/q \leq 6$ [1]. For ISAC-II a beam of 1.5MeV/u is delivered from the exit of IH-DTL5 of ISAC-I to the entrance of the medium β section of the SC linac via a 25m transfer line. In the second stage of the ISAC-II upgrade, an additional 20 superconducting high beta cavities will be added in the same accelerating vault to produce an accelerating voltage of 20 MV for masses up to 150, with $A/q \leq 7$. The medium beta cavities employ 106 MHz tube amplifiers whereas the rf amplifiers for the high beta cavities operating at 141 MHz will be decided soon.

ISAC

ISAC-I

The ISAC–I heavy ion linac is composed of room temperature rf structures operating at various rf frequencies [2]. Figure 1 shows the layout of the accelerator as well as the S-bend transfer line joining ISAC-I and ISAC-II. Table 1 shows the list of room temperature rf structures and rf amplifiers with power requirements for the accelerating voltages. ISAC-I has been operational since 2000 with excellent performance [3]. Some of the re-furbishing and improvements that were carried out are mentioned here. The RFQ which was operational since 1999 was opened in 2006 spring shutdown since the vacuum deteriorated to $2x10^{-6}$ from $5x10^{-7}$ Torr. Water leaks in two of the split ring resonators of the RFQ and cooling line brazing joints were the major cause for poor vacuum. They were replaced with two identical rings and joints were repaired.

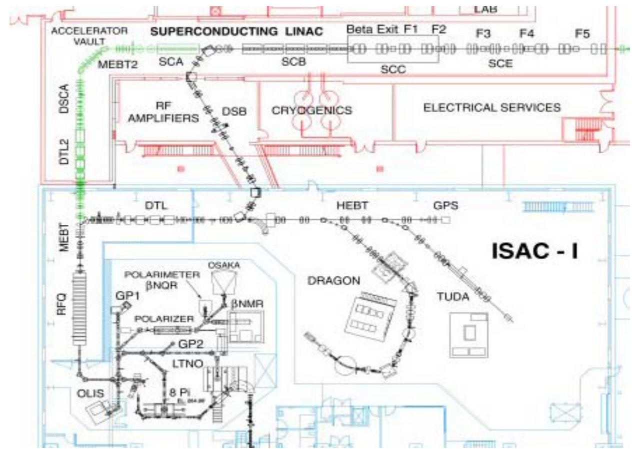

Figure 1: Layout of ISAC linear accelerator

Table 1: ISAC-I Room Temperature RF Structures

RF Device	RF Structure Type	Frequency	Electrode Voltage	Nominal Power
		MHz	V	P
Prebuncher	Parallel Plates	11, 23, 35	400 V	500 W
RFQ	Split Ring 4 Rod	35.36	74 kV	80 kW
Bunch Rotator	Split Ring	106.08	35.5 kV	3.5 kW
Chopper	Coil + Parallel Plates	5.89	5.5 kV	45 W
Chopper	Coil + Parallel Plates	11.78	7.4 kV	140 W
Rebuncher	Spiral	35.36	30 kV	1 kW
DTL Tank1	IH	106.08	47 kV	3.9 kW
Buncher 1	Split Ring	106.08	55 kV	8 kW
DTL Tank2	IH	106.08	69 kV	10 kW
Buncher 2	Split Ring	106.08	74 kV	10.2 kW
DTL Tank3	IH	106.08	97 kV	16 kW
Buncher 3	Split Ring	106.08	91 kV	11.6 kW
DTL Tank4	IH	106.08	109 kV	19 kW
DTL Tank5	Split Ring	106.08	116 kV	20.3 kW
Low Beta Buncher	Coil + Drift Tube	11.78	30 kV	1.5 kW
High Beta Buncher	Spiral	35.36	170 kV	12.6 kW
S-bend buncher	Spiral	35.36	170 kV	12.6 kW

The most probable cause is due the use of very aggressive flux which was applied for soldering of copper and stainless steel joints. This material was excluded from the MS manufacturing process in 2002.

The DTL tank 1 cooling channels, drilled in the mild steel end plates and nickel plated, lately showed corrosion and water contamination. An external water-cooling on the end plate was designed and implemented to eliminate this problem. The DTL amplifiers also went through some modifications. All five DTL amplifiers were installed with a new high voltage proof circuit. In addition the amplifier status signals and DC voltage, current and rf parameters were incorporated in a new remote control system to facilitate operation.

Transfer Line

The transfer line buncher is identical to the HEBT 2-gap spiral buncher operating at 35 MHz. It's rf amplifier, built in-house, employs a power tetrode EIMAC 4CW25000A. The buncher-amplifier system has been tested up to 13 kW of power equivalent to 170 kV gap voltage. A fine tuner without finger stock was successfully installed in this buncher with a maximum temperature increase of 15^0C in the tuner parts. The same tuner modification has being implemented in DTL tanks 2-5.

ISAC–II

The medium beta cavities employed in ISAC-II are two-gap bulk niobium quarter wave structures. The first eight cavities are designed for particle velocity β = 5.7 % while the remaining 12 have a β of 7.1 % [4]. These cavities provide an average gradient of 7 MV/m with power dissipated, P_{cav}= 7 W exceeding the design gradient of 6 MV/m. The gradient corresponds to an acceleration voltage of 1.26 MV per cavity with a peak surface field of 35 MV/m. Figure 2 shows the accelerating gradients for all 20 cavities installed in the beam line.

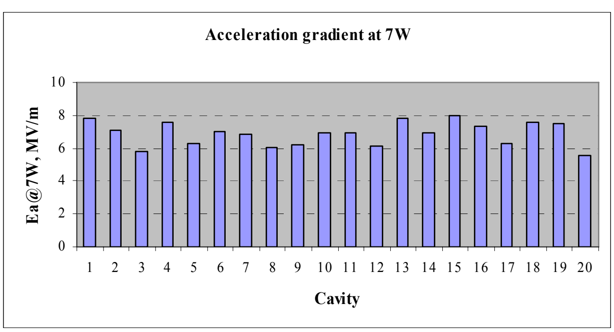

Figure 2: Gradients of 20 cavities with 7 W rf power

These 20 cavities are housed in five cryomodules with four cavities and one superconducting solenoid in each cryomodule. The equipments for cryomodule vacuum pumps and sensors, heater power supplies, rf power amplifiers and rf control system, cavity tuner motor drivers and control, dc power supplies for superconducting solenoid and xy-steer are installed in the power supply room which is adjacent to the ISAC-II accelerator vault. The arrangements of the equipments have been modular so that one row of equipment feed one cryomodule. At the end of each row, there is a BOP (break out panel) which houses the EPICS interface providing operation of the accelerator from the control room. Figure 3 shows the equipment layout in the power supply room. Two racks close to the wall house four rf amplifiers for each cryomodule.

Figure 3: Power supply room equipment layout

Medium Beta RF

The rf amplifiers for the medium beta linac, a total of 20, operate at 106.08 MHz and are interfaced with EPICS. Although rf power required for each cavity is 7 W, much more power is delivered from the rf amplifier. The movable coupling loop associated with each cavity is providing over coupling in order to increase the bandwidth and thus enabling rf controls to suppress the micro-phonics effects. The power required for nominal operation is 150 watts. The amplifiers are capable of delivering 800 watts for pulse conditioning of the cavities. ISAC safety requires that the rf amplifiers to be interlocked such that rf can not be turned on when the medium beta cavities are cooled to liquid helium temperature and the vault door is open. This safety interlock and remote operation has been fully established as a pre-condition to get a license to power the linac cavities

The rf control system for the medium beta superconducting cavities is a hybrid of analog and digital system. Each system consists of a self-excited feedback loop with phase-locked loops for stabilizing phase and frequency of the accelerating cavities. Amplitude and phase regulation is also performed by the rf control system by using digital signal processing. The gain linearity from 4 to 200 watts is specified to be within ± 0.5 dB and the phase stability to be < ± 5 degree. An important parameter is phase noise of the rf system within 1 - 200 Hz bandwidth. Figure 4 shows the measured phase noise of SCB1, cavity 4, where SCB stands for medium beta section. The integrated value of phase noise within the specified bandwidth meets the linac specification of < ±1 degree.

High Beta RF

The second stage of ISAC-II is to install 20 bulk niobium high beta quarter wave cavities operating at 141 MHz [5]. These cavities are divided into two modules of six cavities and one module of eight cavities with one superconducting solenoid in each cryomodule. Table 2 summarizes the parameters of the 106 MHz medium beta cavities and 141 MHz high beta cavities. The power requirements from the rf amplifier is similar to the 106 MHz amplifier.

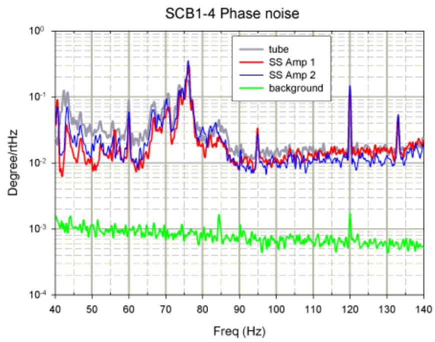

Figure 4: Phase noise spectra for SCB cavity with solid state and tube amplifiers

Table 2: ISAC-II Medium Beta and High Beta Cavities

		Medium Beta		High Beta
Parameters	unit	flat	round	round
f_0	MHz	106	106	141
Active length	mm	180	180	180
Ea	MV/m	6	6	6
U/Ea2	J/(MV/m)2	0.1	0.093	0.073
Bp/Ea	mT/(MV/m)2	10.3	10.1	10.3
Ep/Ea		5.2	4.7	4.7
Va @ 6MV/m	MV/m	1.08	1.08	1.08
Power @ 6MV/m	W	4.6	4.5	4.0
Mech. frequency	Hz	80	80	150

Tube and Solid State Amplifier

Considerable experience has been gained from running the installed tube amplifiers for ISAC-II medium beta linac. The rf performance of these tube amplifiers have been compared with solid state amplifiers operating at 200 Watts. Although both type of amplifiers satisfy the gain and the phase linearity requirement, phase noise for the solid state amplifier is lower in the 40 - 140 Hz band. This can be seen in figure 4. AC ripple at 60 Hz and 120 Hz of the high voltage dc power supply of the tube amplifier are the main contributors to the higher phase noise. Solid state amplifiers employ low dc voltage, high current switching mode power supplies hence low frequency AC ripple is non existent.

Long term phase drift of the grid tube amplifier poses a significant challenge to the control system. Both prototype tube amplifier and solid state amplifier have been tested for long term phase drift. The tube amplifier has a 15 degree phase shift for the first 15 minutes of rf start up at 250 Watts. The solid state amplifier produces only 2^0 phase drift in the first two minutes. Both tube and solid state amplifiers, however do not drift in phase after the initial worm up.

Tube life can be extended by employing filament power management for tubes with a thoriated tungsten emitter [6]. This is based on measured loss of carbon as a function of temperature. For 400 Watt output power for the 106 MHz rf amplifiers, tube anode current changes from 0.46 A to 0.45 A when the filament power is reduced from 100% to 80%. This produces relative life extension probability by a factor of two as shown in figure 5. This power management will be implemented in all the 20 power amplifiers to get extended tube life.

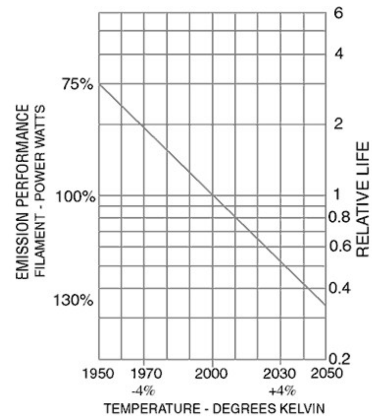

Figure 5: Extension of tube life by filament power management

Although the solid state amplifiers are more expensive than the tube amplifier, low phase noise, small phase drift, broad bandwidth and long device life make them an attractive choice for 141 MHz ISAC-II high beta linac.

CONCLUSIONS

The ISAC-I rf system worked very reliably since they were commissioned. ISAC-II medium beta rf amplifiers have just been installed and have worked in conjunction with the rf control to test and commission the medium beta linac. Steps are being taken to increase the tube life beyond their normal expected life. Although solid state amplifiers are more expensive than the tube amplifiers, they are being considered for high beta rf system.

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