COMMISSIONING OF THE ISAC-II SUPERCONDUCTING LINAC AT TRIUMF

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Abstract

A heavy ion superconducting linac with a total accelerating voltage of 20 MV is now installed at TRIUMF as an energy booster to the ISAC room temperature linac for the acceleration of radioactive beams. Heavy ion beams from 4He to 40Ca have been accelerated with final energies consistent with an operating gradient of 7.2 MV/m and an average peak surface field of 36 MV/m. This represents the highest gradient of any operating heavy ion cw linac in the world. The commissioning results and methods are reported.

INTRODUCTION

TRIUMF has installed a new heavy ion superconducting linac as an extension to the ISAC facility [1], to add ~20 MV of accelerating voltage to the existing room temperature linac capability of 1.5 MeV/u for ions with $A/q \leq 6$. An achromatic transfer line transports the beam from ISAC to the ISAC-II accelerator vault. The superconducting linac is composed of bulk niobium, quarter wave, rf cavities, for acceleration, and superconducting solenoids, for periodic transverse focussing, housed in several cryomodules. The initial five cryomodules represent a first stage with a further 20 MV of superconducting linac to be installed over the next three years.

The present installation consists of twenty 106 MHz quarter wave cavities. Each cavity consists of only two accelerating gaps giving a broad velocity acceptance. Eight of the cavities have a design beta of 5.7% with the remaining twelve having a design beta of 7.1% (Fig. 1). The ISAC-II medium beta cavity design goal is to operate up to 6 MV/m across an 18 cm effective length with $P_{\rm cav} \leq 7$ W. The gradient corresponds to an acceleration voltage of 1.1 MV, a challenging peak surface field of $E_p = 30$ MV/m, a peak magnetic field of 60 mT and a stored energy of $U_o = 3.2$ J and is a significant increase over other operating heavy ion facilities. Several design and hardware choices were made in an effort to reach the goal such as an LN2 cooled coupling loop [2] and a high performance zero backlash tuner[3]. For simplicity of mechanical assembly a single vacuum space for cavity and thermal isolation is used but clean assembly methods and cavity rinsing are adopted. The accelerator lattice is compatible with the strong defocussing associated with high gradient cavities. Also unique is the use of unshielded high field solenoids with added cancelling coils operating in close proximity to the cavities[4].

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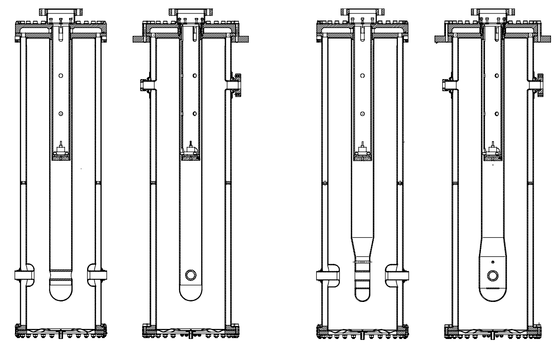

Figure 1: The two medium beta quarter wave cavities for the ISAC-II linac.

LINAC PREPARATION

All cavities are characterized via cold test in a single cavity test cryostat prior to mounting in the cryomodule[5]. Some cavities received repeated tests depending on the initial performance. Prior to installation all twenty cavities met or exceeded ISAC-II specifications for frequency and performance. The average peak surface field of 38 MV/m corresponds to a gradient of 7.6 MV/m and a voltage gain per cavity of 1.4 MV. Conversely the cavities would consume an average of 3.3W to each produce the design peak surface field of 30 MV/m.

The cryomodule assembly and commissioning off-line tests are conducted in the clean laboratory area in the ISAC-II building. In total ten cold tests were completed in order to characterize and prove the performance of the five cryomodules and establish alignment of the cold mass. Each module has two main assemblies, the top assembly and the tank assembly. The top assembly shown in Fig. 2 includes the vacuum tank lid, the lid mu-metal and LN2 shield, the cold mass and the cold mass support. The tank consists of the vacuum tank, the mu-metal liner and the LN2 box insert. Both the top and bottom sub-components were assembled separately in a 'dirty assembly' area as a pre-assembly step. The sub-components were then disassembled, cleaned and delivered to the ISAC-II clean room for final assembly, alignment and testing. The top assembly is assembled in the Class III cleanest area. The tank is installed in the test pit in the Class II area that is serviced with an overhead crane. After completion the top assembly is moved to the Class II area and inserted in the tank assembly for cooldown and rf testing.

The cold mass elements are pre-aligned warm to off-sets determined in the intial cooldowns. Optical targets inserted

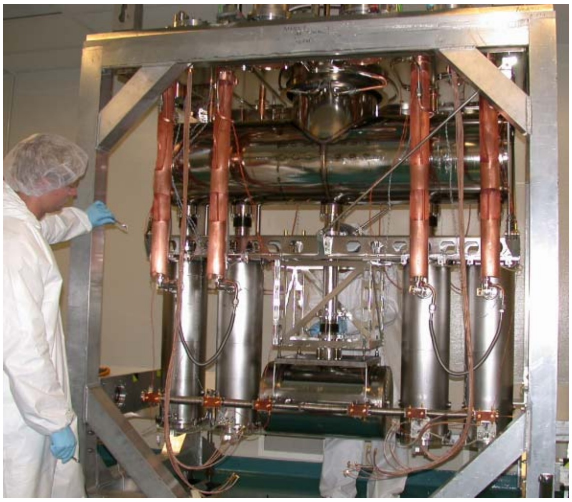

Figure 2: Cryomodule top assembly in the assembly frame prior to the cold test.

in the solenoid are used to align the cold mass with respect to the tank beam ports once thermalization is reached. After the final cold test the top assembly is opened to remove the targets then re-installed, pumped down and moved to the vault. Alignment in the vault is done with optical targets in the tank beam ports. A view of the final vault installation is shown in Fig. 3

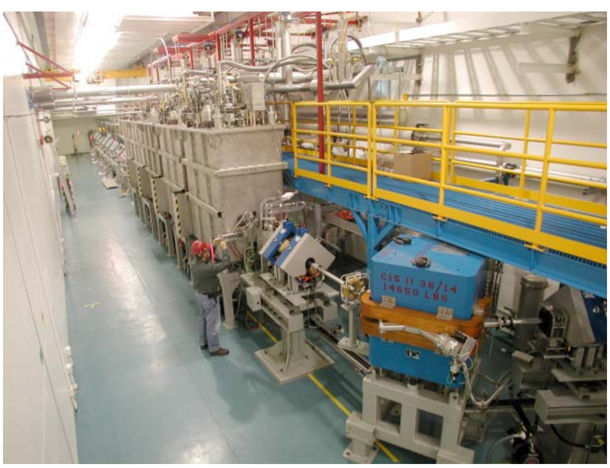

Figure 3: The ISAC-II accelerator vault.

CRYOGENICS

The linac cryomodules are cooled by 4K LHe at 1.1 Bar. The measured static heat load for a single cryomodule is ∼13 W with a LN2 feed of 5 ltr/hr. Together with estimated thermal losses from the cold distribution of 85 W this gives a total static load of 150 W. The budget for active load component is 8 W per cavity giving 160 W for the twenty medium beta cavities for a total estimated heat load of 310 W. A TC50 Linde cold box complete with oil removal and gas management system, main and recovery compressors is installed and commissioned. The measured refrigeration power with LN2 precooling is 610 W at 0.7gm/sec liquifaction. In addition three turn down modes are possible by utilizing the variable frequency drive on the main compressor corresponding to peak refrigeration power of 375 W, 280 W and 190W and fractional wall power of 0.7, 0.59 and 0.53 respectively compared to the full output. The demonstrated liquifaction rate based on a rising dewar level is 225 ltr/hr. There is a periodic slow oscillation of the suction pressure of ~ 10 mbar peak to peak that can be accomodated by the ISAC-II tuners.

The refrigerator supplies liquid helium to a dewar. The cold helium piping is supplied by Demaco to TRIUMF's specification. The main linac manifold supply line is fed LHe from the dewar via a small overpressure. The cryomodules are fed in parallel from this helium supply 'trunk' line through variable supply valves and field joints. The cold return from the cryomodules comes back to the trunk cold return line through open/close valves and field joints. During cooldown, when warmer than 30°K, the returning gas is sent back to the suction side of the compressor through the warm return piping and in-line vaporizers. Keep cold sections with proportional valves join the trunk supply and the trunk cold return at each end. All supply and cold return piping is vacuum jacketed and except for the short cryomodule feed lines is cooled with LN2.

Cooldown

The cavities are first baked at ∼90°C for 48 hours. LN2 is then fed through the side-shields and the cold mass is cooled by radiation for at least 48 hours to bring the average temperature to about 200K before helium transfer. On two of the cryomodule cold tests we have had problems with one or more cavities having an open connection on the rf feed. These open connections close after warming. The hypothesis is that the thermal contraction on cooldown is responsible for the open circuit. The procedure now is to regulate the LN2 flow to slow the cooldown rate. This has been sufficient to eliminate the problem to date.

Linac cooldown is done sequentially, one cryomodule at a time, to achieve a cavity cooling rate of ∼100K/hour to mitigate the effects of Q-disease.[5] This requires a LHe flow of ∼100-150 ltr/hr. It takes about five hours to establish a 120 ltr inventory in the cryomodule and roughly 24 hours to complete the bulk of the thermalization. A full cooldown takes a minimum of seven days with two days for the cold box, dewar and trunk line and one day each for the cryomodules. After each module is filled it remains at level even as the warm modules are cooled. A level probe in the cryomodule helium reservoir is used to regulate the variable supply valve during operation.

ACCELERATION TESTS

Acceleration commissioning is done using stable beams from the ISAC off-line ion source. The beams are accelerated to 1.5MeV/u and transported to ISAC-II via a 25 m S-bend transport line complete with a 35 MHz two gap spiral buncher for longitudinal matching to the new linac. Acceleration commissioning runs are scheduled between experimental physics beam delivery periods with a frequency of about once per month.

Diagnostics

A silicon detector downstream of the linac monitors ions back scattered from a thin gold foil. The monitor is used for cavity phasing and energy measurement. A time of flight monitor in the downstream beamline is used for more precise energy measurement. The monitor consists of two identical units spaced 9.2 m apart. Each unit consists of a biased wire inside a grounded can. A hole in the can allows the beam to pass. Electrons driven off the wire are accelerated through an aperture in the can to a micro-channel plate for timing information. The response and delay times of the monitors are pre-set by a laser calibration on a test bench. The distance between the monitors is measured by an alignment laser. Beams of known energy from the ISAC are used to cross check the accuracy of the TOF monitor.

Measurements

The rf cavities are initially pulsed conditioned to optimize performance where required. An initial beam acceleration was done with cavities averaging 6 MV/m with about 4 W/cavity. For the next and all subsequent runs the cavities are set to the power limit of 7 W per cavity at critical coupling. The coupler is then moved to a position requiring a forward power of ∼160 W for a coupling β ∼100 that provides sufficient rf bandwidth to maintain lock. The cavities are initially locked and left for twenty-four hours to test the operational stability and tuner perfomance.

Six different beams have been accelerated to date corresponding to three different mass to charge ratios; 40Ca10+, 22Ne4+, 20Ne5+, 12C3+, 4He1+ and 4He2+ with A/q ratios of 2, 4 and 5.5. Beams from ISAC at two different reference energies are delivered and coasted through the linac to calibrate the silicon detector. The S-bend buncher is tuned using the silicon detector and acceleration begins. Each cavity is turned on starting at the upstream end. The cavities are phased by measuring the beam energy for four different phases and fitting the data to a cosine profile to find 0°. All cavities are set to a sychronous phase of -25° for acceleration. The focussing solenoids and beamline optics are set to their theoretical settings as the acceleration progresses. Acceleration results are shown in Fig. 4(b) compared to expected final energies assuming the design gradient of 6 MV/m. Final energies of 10.8, 6.8 and 5.5 MeV/u are reached for beams with A/q values of 2, 4 and 5.5 respectively. The average cavity gradients for the three cases as calculated from the acceleration rate are shown in Fig. 4(a). The average gradient in each case is 7.2 MV/m corresponding to an average peak surface field of 36 MV/m and an average voltage gain of 1.3 MV/cavity. Single cavity rf test results for each cavity are plotted for comparison. The gradients in general match well the gradients from initial single cavity tests. A few cavities have obviously been contaminated during assembly and others have improved perhaps during the final assembly rinse. The average operating gradient is down by only 5% from the single cavity result. Furthermore over the first three months of commissioning the average gradient has not deteriorated. Transmission is >90% and the tuning is straightforward.

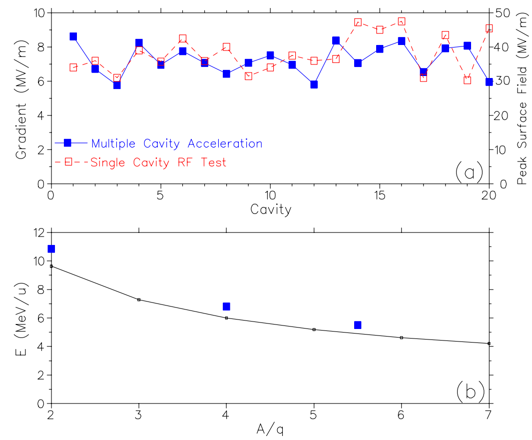

Figure 4: (a) Average cavity gradients for the three A/q values and for 7 W cavity power. Results are inferred from the step energy gain per cavity during acceleration. Also shown are gradients from initial single cavity characterizations. (b) Final energies for the three cases compared to expected final energies assuming the design gradient of 6 MV/m.

CONCLUSION

The performance represents the highest accelerating gradient for any operating cw heavy ion linac in the world. Initial commissioning runs have concentrated on completing measurements in support of our operating license. Further runs will be devoted to measuring beam quality and improving application programs in support of beam delivery. First experiments with radioactive beams are scheduled for Oct. 2006.

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