ISAC-II SUPERCONDUCTING LINAC UPGRADE - DESIGN AND STATUS

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Abstract

The ISAC-II superconducting linac, operational since April 2006, adds 20 MV accelerating potential to the ISAC Radioactive Ion Beam (RIB) facility. An upgrade to the linac, in progress, calls for the addition of a further 20 MV of accelerating structure by the end of 2009. The new installation consists of twenty 141 MHz quarter wave cavities at β_0=11%. The cavities will be housed in three cryomodules with six cavities in the first two cryomodules and eight cavities in the last. A second Linde TC50 refrigerator has been installed and commissioned to provide cooling for the new installation. The design incorporates several new features as improvements to the existing cryomodules. A summary of the design and the current status of the cryomodule production and supporting infrastructure will be presented.

INTRODUCTION

The Radioactive Ion Beam (RIB) facility, ISAC, includes an ISOL production facility and a post-accelerator for delivery of beams from 150 keV/u to beyond the Coulomb barrier.[1] The post-accelerator consists of two room temperature devices, a 35 MHz RFQ for acceleration of ions with A$\leq$30 to 150 keV/u and a 106 MHz post-stripper DTL to energies fully variable from 0.15 to 1.8 MeV/u. A superconducting heavy ion linac[2] was added in 2006 to add a further 20 MV to the ISAC beam energy. The installation known as ISAC-II is the first phase in a planned three phase installation. The Phase I linac consists of 20 bulk niobium quarter wave cavities housed in five cryomodules. Each cryomodule consists of four cavities and one superconducting solenoid arranged symmetrically along the beamline with a diagnostic box and steering magnet located between the modules at the beam waist. Routine average operating gradients of 7 MV/m corresponding to peak surface fields of 35 MV/m are achieved. Eight of the cavities (the first two cryomodules) are β=0.057 and the other twelve are β=0.071.

A second phase now in progress will see the addition of another 20 MV of accelerating potential to extend the present energy range by the end of 2009. The new installation consists of twenty 141 MHz quarter wave cavities at β=0.11. The cavities will be housed in three cryomodules with six cavities in the first two cryomodules and eight cavities in the last. The cavities and cryomodules are now in fabrication. The plan is to install the completed and tested cryomodules during an extended shutdown of ISAC-II starting in Sept. 2009. The layout of ISAC-I and ISAC-II is shown in Fig. 1.

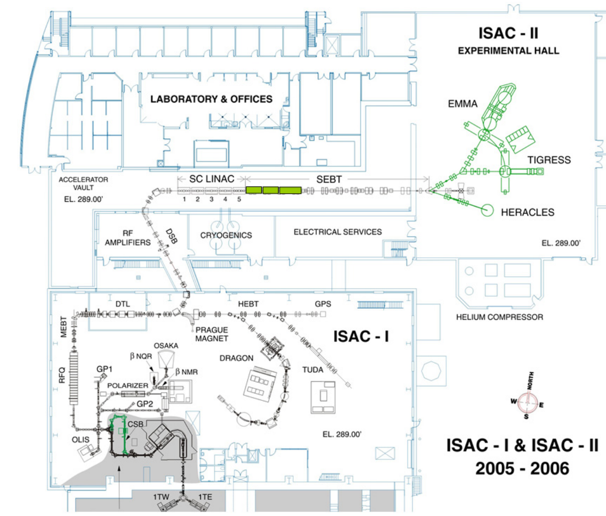

Figure 1: The layout of ISAC-I and ISAC-II. The Phase II SC-linac is highlighted.

CRYOMODULE DESIGN AND STATUS

The Phase II cryomodules are identical in many respects compared to the Phase I cryomodules. A key design choice was to maintain the philosophy of incorporating a single vacuum space for thermal isolation and beam/rf volumes. This has been the historic choice in the low-beta community (ATLAS, INFN-Legnaro, JAERI) but recent proposed facilities in development or assembly have chosen separated vacuum systems (SARAF, SPIRAL-II, FRIB). The decision to maintain a single vacuum comes from our experience with Phase I operation of the SC-linac. We have seen very little evidence of degradation in cavity performance over the first two years of operation even after repeated thermal and venting cycles. Procedures are followed to help mitigate cavity degradation: 1. Initial cavity treatment and overall assembly using HPWR and clean conditions 2. Vacuum materials and components to be free from particulate, grease, flux and other volatiles 3. Maintain a LN2 cooled cold trap upstream and downstream of the linac to prevent volatiles migrating from the beamline into the cryomodule 4. Cryomodule venting with filtered nitrogen 5. Pumping and venting of modules at slow rates to avoid turbulences.

All cryomodules are assembled in a ‘dirty’ assembly area to check the fitting of all components. Next the assembly is completely dismantled, all parts are cleaned in

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an ultrasound bath, rinsed with 18 MΩ water at high pressure and dried in a clean room before assembly.

There are some differences between the Phase I and Phase II cryomodules that either address small deficiencies in the Phase I design or are required due to the longer size of the Phase II cryomodules: 1. The vacuum tanks are essentially the same with dimensional differences to accommodate the internal components. The eight cavity SCC3 has an extra set of ribs on the lid and sides to reduce vacuum deformation on the larger areas. The mounting footprint is also elongated to give more stability. 2. The cavities and solenoid are supported from a rigid strongback that is in turn supported from the tank lid by support rods. In the SCB cryomodules a three point mounting system was used to suspend the strongback. The decision here is to adopt a four point system to reduce the freedom in the movement of the cold mass. The strongback assembly is considerably more robust than in the SCB due to the increased cold mass and length. 3. In the SCB the LN2 cooling for the side shields and the coupling loop is one series circuit. In the SCC the delivery to the coupling loops is achieved with parallel channels to reduce the size of the fittings on the coupling loop. 4. The solenoid mounting system is completely modified in SCC and is based on a linked strut system to aid in alignment. 5. The helium reservoir is redesigned with thicker wall material and a purchased tee section. Bulkheads are incorporated into the weld seams to make all welds external. The service stack for the helium space is now outfitted with a 12.5 cm high spool piece with the feedthroughs and ports for all of the cryogenic and vacuum diagnostics. Provision for level sensor replacement has been added with ports on the top of the reservoir. Cables and He distribution lines are installed before final weld on each end of the reservoir. The welding is done in place of the SCB indium seals that were prone to cold leaks. 6. The mu metal thickness has been increased from 1 mm to 1.5 mm.

Present Status

All three vacuum chambers and lids have been received. Mu metal has been installed on two of the vacuum chambers. The LN2 side shields panels have been fabricated and the shield box assembly is almost complete. Dirty assembly of the first cryomodule is underway. The effect of the mu metal has been characterized and reaches the specified remnant field criterion of <20mG.

SUPERCONDUCTING CAVITIES

The cavities for Phase II are quarter wave bulk niobium with features similar to the Phase I cavities. In this case the rf frequency of 141.4 MHz (the 12th harmonic of the bunch frequency 11.8 MHz) allows to keep the same outer conductor dimension while increasing the design velocity to β=0.11. The cavity has been outfitted with a beam tube (donut) to symmetrize the transverse rf fields and improve the transit time factor. The cavity is shown in Fig. 2.

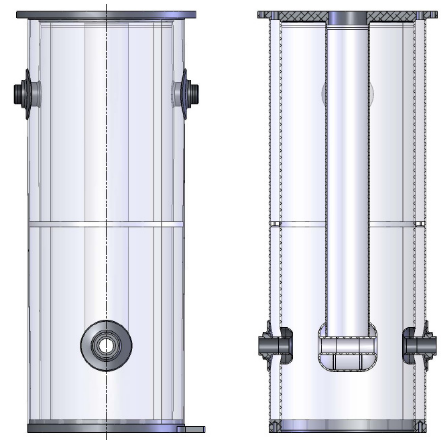

Figure 2: The 141.44MHz rf cavity for Phase II.

The cavities are being produced by Pavac Industries of Richmond BC Canada. The development included the manufacture of two full size copper models to study all of the machining, assembly, tuning and welding steps. Two Niobium cavities have been produced.[3] The cold test results of the two prototypes are shown in Fig. 3. Note that the ISAC-II specification of $E_a = 6$ MV/m at 7W (E_p=30 MV/m) is exceeded by a comfortable margin with average values of $E_a = 8.5$ MV/m ($E_p > 40$ MV/m). PAVAC is presently completing the first six production cavities as well as machining the rest of the parts for the remaining fourteen cavities in preparation for welding.

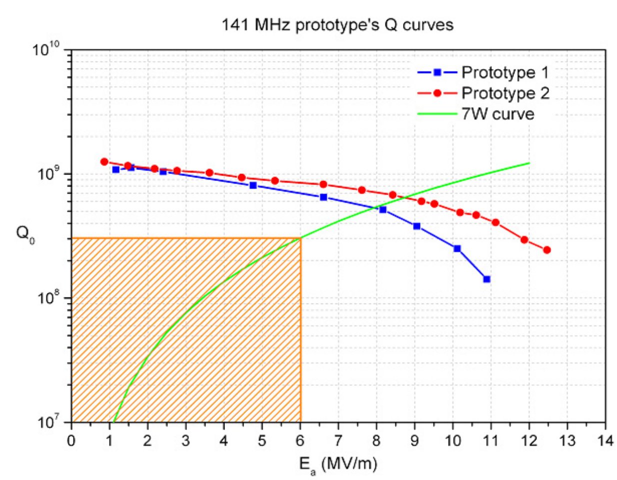

Figure 3: Characterization curves of the two 141 MHz QWR cavities.

RF ANCILLARIES

Amplifiers

As part of the upgrade of the ISAC-II superconducting linac, twenty solid state amplifiers have been ordered with QEI Corporation, NJ, USA. A prototype amplifier has been tested thoroughly prior to series production. The gain of the amplifier, the 3 dB bandwidth and output power were measured and are within the specification. Gain linearity is within ±0.5 dB and phase linearity is within ±2.0 dB for the output power range from 1 to 250 watts. The amplifier gain is measured to be 65 ± 0.75 dB, which is 10 dB higher than specified. The phase noise of the prototype amplifier is estimated by tests into both a dummy load and one of the prototype cavities. These measurements are compared to the same values using a tube amplifier. The solid state amplifier is significantly less noisy than the tube amplifier. For the solid state amplifier the average noise value is 0.0044° rms in the frequency range of 2-200 Hz. The average noise for the tube amplifier in the same frequency range is 0.098° rms. The integrated value of phase noise in the bandwidth of $2 - 200$ Hz was specified to be less than 0.3° rms. These amplifiers will be installed in the power supply room adjacent to the accelerator vault.

Mechanical Tuner

In the Phase I system the cavities are tuned by a lever arm that pushes against a tuner plate on the bottom end of the cavity. The lever arm is actuated by a long push rod that extends to the top of the cryomodule through a bellows to a linear servo motor[4]. The system works well and provides high performance tuning for high gradient operation. The tuner motor is an expensive item and development work subsequent to the Phase I installation has resulted in a new design using a ball screw drive to replace the linear motor. The brush-less servomotor contains its own single turn absolute sine encoder. The power and encoder signals are connected through long cables to a matched digital servo-amplifier. The output shaft of the motor is connected directly to the anti-backlash internally preloaded precision ball screw nut, through a stiff bellows coupling. The anti-backlash nut is fixed rigidly to the anti-backlash liner guides that provide perfectly reproducible vertical straight-line motion resulting in a vertical position resolution of at least 0.03 μm with a positioning bandwidth of at least 30 Hz. The interface connections are designed to retrofit the SCB low beta SRF tuner rod connector design.

Coupling Loop

The SCB variable coupling loop[5] uses a Teflon bearing but side loads from the LN2 cooling lines cause some stiffness in the mechanical motion at cold temperature. A redesigned coupling loop with non-magnetic cross-roller bearings and symmetric loading has greatly improved the mechanical motion and the new design is being employed in SCC.

CRYOGENIC SYSTEM

The Phase I cryogenic system consists of a Linde TC50 cold box configured with a 79 gm/sec KAESER compressor. Helium produced in the cold box is fed to a 1000 liter dewar. The LHe is delivered to the cryomodules at 4K through vacuum jacketed LN2 cooled helium transfer lines with a slight overpressure in the dewar. The cryomodules are fed in parallel from a main supply manifold (trunk) through variable supply valves. The level in the cryomodules is used to control the opening of the supply valves. The vapour from the cryomodules is returned either in a warm return line direct to the compressor during cooldown or through a cold return line back to the cold box during normal operation.

The Phase II addition of the cryogenic system (shown in Fig.4) essentially duplicates the Phase I system. A second Linde plant has been installed identical in every respect to Phase I except that a second recovery compressor was not ordered. The system has been installed by TRIUMF and commissioned. The measured liquefaction with LN2 precool is 240 ltr/hour and the refrigeration power is 600 W. The stability of the helium pressure is within ±7 mBar.

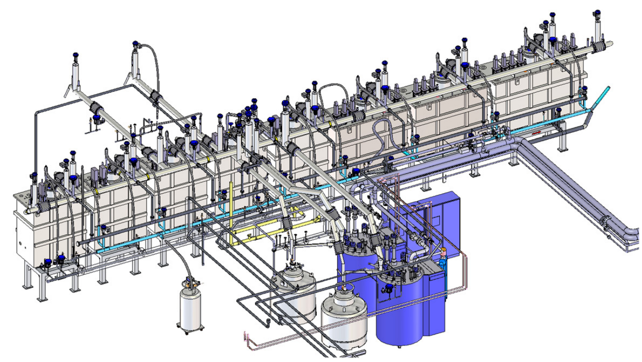

Figure 4: The cryogenics system for ISAC-II Phase I and II.

SUMMARY

The phase II system is on schedule for completion by the end of 2009. The first six cavities are expected by the end of October. The cavities will be processed (BCP) and tested at TRIUMF before mounting into the first cryomodule for cryogenic and alignment tests. The other two cryomodules will follow with full installation by Dec. 2009.

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