

# SCRF ACTIVITIES FOR THE ISAC-II UPGRADE AT TRIUMF

R.E. Laxdal, Y. Bylinsky, G. Dutto, K. Fong, A.K. Mitra, R. Poirier, W. Rawnsley, T. Ries, I. Sekachev, G. Stanford, TRIUMF\*, 4004 Wesbrook Mall, Vancouver, Canada, V6T2A3

## Abstract

TRIUMF is proceeding with a major upgrade to the ISAC project, ISAC-II, that includes the addition of 43 MV of heavy ion superconducting linear accelerator and an ECR charge state booster. An initial installation of 18 MV of mid beta cavities ( $\beta = 5.8\%$ ,  $7.1\%$ ) is due for commissioning in 2005. The paper will describe the superconducting linac program at TRIUMF including the status of the production cavities, the design of the medium beta cryomodule and a summary of the activities of the SCRF laboratory.

## INTRODUCTION

TRIUMF is now constructing an extension to the ISAC facility, ISAC-II, [1], to permit acceleration of radioactive ion beams up to energies of at least 6.5 MeV/u for masses up to 150. In brief the proposed acceleration scheme would use the existing ISAC RFQ ( $E = 150$  keV/u) with the addition of an ECR charge state booster to achieve the required mass to charge ratio ( $A/q \leq 30$ ) for masses up to 150. A new room temperature IH-DTL would accelerate the beam from the RFQ to 400 keV/u followed by a post-stripper heavy ion superconducting linac designed to accelerate ions of  $A/q \leq 7$  to the final energy.

The superconducting linac is composed of two-gap, bulk niobium, quarter wave rf cavities, for acceleration, and superconducting solenoids, for periodic transverse focussing, housed in several cryomodules. The linac is grouped into low, medium and high beta sections corresponding to cavities with design velocities of  $\beta_o = 4.2\%$ ,  $\beta_o = 5.7, 7.1\%$  and  $\beta_o = 10.4\%$  respectively. The eight low beta cavities are housed in one long cryomodule with three solenoids interspersed between cavities. The twenty medium beta cavities are installed four per cryomodule in a total of five modules. Twenty high beta cavities are divided into two modules of six cavities and one module of eight cavities. Each of the medium and high beta cryomodules are equipped with one solenoid each.

Due to experimental pressure and budget limitations the installation of the linac has been grouped into three stages highlighted in Fig. 1. The initial Stage 0 to be completed in 2005 includes the installation of a transfer line from the ISAC DTL ( $E = 1.5$  MeV/u) and the medium beta section to produce 18 MV of accelerating voltage for initial experiments. Stage 1 to be completed two years later includes the installation of the three high beta modules for a further 18 MV. The ISAC-II accelerator final Stage 2 is foreseen

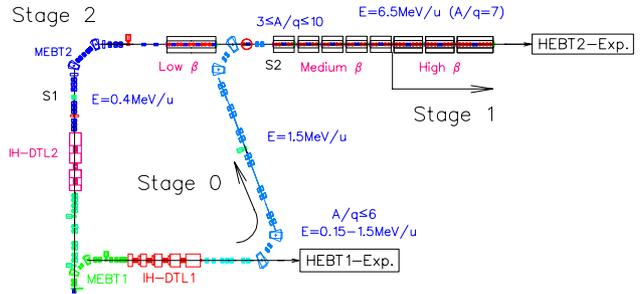


Figure 1: Stages 0, 1 and 2 for the ISAC-II upgrade.

for 2010. A new building complete with linac vault, experimental areas, office and laboratory is now complete. Present studies are concentrating on design and development for the first stage installation.

## HARDWARE AND DEVELOPMENT

Work is ongoing on several fronts with the goal of realizing beam delivery in 2005. The first major milestone is the cold test of a completed medium beta cryomodule in late 2003. An SCRF lab is set up in a neighbouring facility where cold tests are on-going at the rate of one per month. A summary of the present developments are given below.

### Superconducting RF Systems

The ISAC-II medium beta design gradient is 6 MV/m giving a stored energy of  $U_o = 3.2$  J. The natural bandwidth of  $\pm 0.1$  Hz is broadened by overcoupling. The required forward power on resonance is given by  $P_f(W) \simeq \pi U_o \Delta f_{\frac{1}{2}}$  for overcoupled systems. The goal for the ISAC-II cavity tuner is to achieve fine (1 Hz) tuning capability with a response time to control fast helium pressure fluctuations allowing stable operation within a bandwidth of  $\Delta f_{\frac{1}{2}} = 20$  Hz. This requires an rf system capable of delivering  $P_f = 200$  W at the cavity. A set of four rack mounted 1 kW amplifiers with built in circulator and common driver supply have been acquired for the prototype cryomodule test for evaluation.

**Rf Controls** The RF Control system [2] for the superconducting cavities is a hybrid analogue/digital system. Each system consists of a self-excited feedback loop with phase-locked loops for phase and frequency stabilization. Amplitude and phase regulations, as well as tuning control, are performed using digital signal processors. Special pulsing circuitry is incorporated into the system to facilitate ‘punching’ through multipactoring. We have demonstrated fixed amplitude and phase regulation at the design gradient

\* TRIUMF receives funding via a contribution agreement through the National Research Council of Canada

with the phase error used to drive the mechanical tuner to maintain cavity frequency.

**LN2 Cooled Coupling Loop** Initial cavity studies at TRIUMF were done with a coupling loop designed at INFN-Legnaro suitable for operation with lower gradients and lower forward power. Tests at higher power indicate an unacceptably large amount of power is deposited at 4 °K. A new coupler is being developed with the goal to reduce the helium load to no more than 1 W at the design gradient of 6 MV/m with  $P_f = 200$  W. The coupler has a stainless steel body for thermal isolation and a copper outer conductor and rf feed line cooled with LN2. Cooling of the inner conductor is achieved by adopting a thermally conducting Aluminum Nitride dielectric localized in the coupling loop. Most recent results using the AlN inserts and with copper braid linked to LN2 providing the thermal sink gives a static loss of 1.4 W into the helium at a forward power of 200 W. A loop with direct cooling via an LN2 cooled pipe soldered into a copper heat exchange block is now assembled and ready for cold test.

**Tuning Plate** The tuning plate consists of 1 mm thick RRR Niobium sheet of 240 mm diameter fixed to the bottom Niobium flange. To increase flexibility the plate is spun with a single ‘oil-can’ convolution and milled with eight radial 1 mm slots. The performance of the slotted plate compares well to flat plate performance in rf cold tests (see Fig. 2). The plate is capable of allowing  $\pm 20$  kHz ( $\pm 3$  mm) of tuning range.

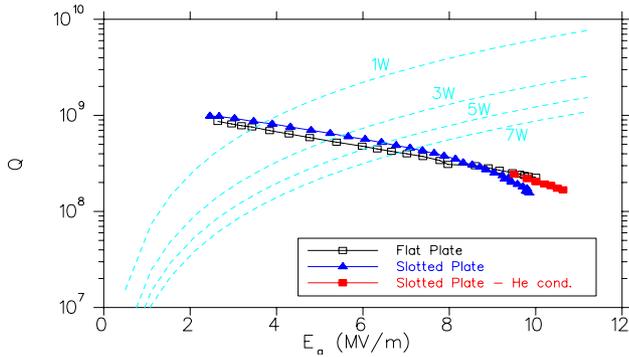


Figure 2: RF cold test results comparing cavity performance with a flat tuner plate and the new slotted plate.

**Mechanical Tuner** A prototype mechanical tuner[3] is now being tested. The tuning plate is actuated by a vertically mounted permanent magnet linear servo motor, at the top of the cryostat, using a ‘zero backlash’ lever and push rod configuration through a bellows feed-through. The system resolution at the tuner plate center is  $\sim 0.055 \mu\text{m}$  (0.3 Hz). The demonstrated dynamic and coarse range of the tuner are  $\pm 4$  kHz and 33 kHz respectively. The tuner on-line performance is measured by altering the cavity frequency by forced variations of the helium pressure. Fig. 3

gives the pressure change, the associated position drive signal for the tuner and the voltage and phase error at the design gradient. The tuner responds accurately to the pressure variation with a resolution better than  $0.1 \mu\text{m}$  (0.6 Hz)[3]. The demonstrated response bandwidth is presently limited to 20 Hz by a mechanical resonance. The phase stability goes out of the regulation tolerance ( $\pm 1^\circ$ ) during moments of rapid pressure change due to the limited power available from the test amplifier.

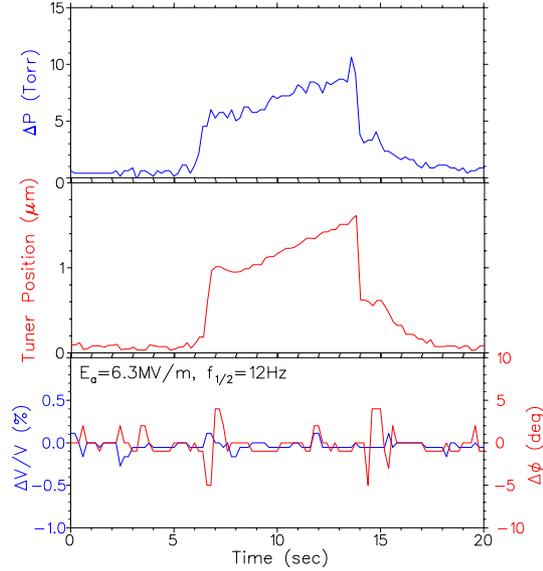


Figure 3: Tuner response to forced helium pressure fluctuation ( $\frac{\Delta f}{\Delta P} = 1 \text{ Hz/Torr}$ ) and corresponding voltage (blue) and phase (red) errors for high field ( $E_a = 6.3 \text{ MV/m}$ ) and a bandwidth of  $\pm 12$  Hz.

**Cavities** A prototype of the  $\beta_o = 7.1\%$  cavity, designed in a collaboration with INFN-LNL, is routinely used for SCRF development tests. The niobium sub-assemblies of the twenty cavities of the medium beta section composed of eight  $\beta_o = 5.7\%$  and twelve  $\beta_o = 7.1\%$  cavities, are being fabricated in industry. Three of the  $\beta_o = 5.7\%$  are fabricated and await final chemical etching while four of the  $\beta_o = 7.1\%$  cavities have been tested. Three of these cavities meet specification but the fourth suffers from a poor  $Q$ . This fourth resonator does have a small dark spot on the rf surface at the root end that developed after chemical polishing. The plan is to recover this cavity with a combination of local hand polishing and further chemical treatment. To keep the schedule the fourth cavity in the first cryomodule will be taken by the prototype cavity. A summary of cold tests for the cavities of the first cryomodule, consisting of three production cavities and the prototype are shown in Fig. 4. All cavities meet the ISAC-II gradient specifications (6 MV/m in 7 W) but the field emission at higher gradients evident in several of the cavities should be reduced through high pressure rinsing and rf conditioning. The remainder of the medium beta cavities should be completed in Oct. 2003.

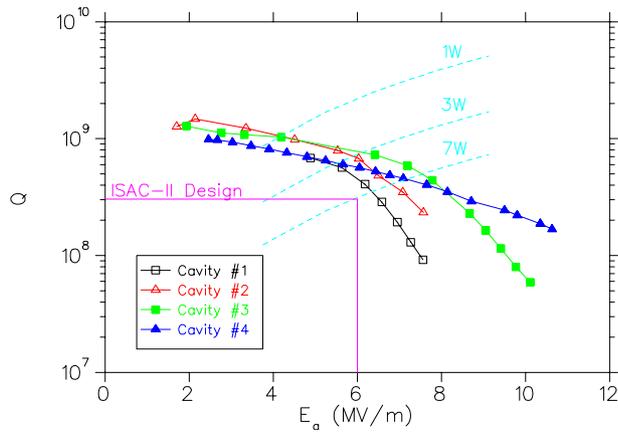


Figure 4: Cold test results for the cavities of the first medium beta cryomodule.

### Medium Beta Cryomodule

A prototype of the medium beta cryomodule Fig. 5, is now in the detail design and fabrication phase. The vacuum tank consists of a stainless steel rectangular box and lid. All services and feedthroughs are located on the lid. Copper sheet cooled with  $\approx 36$  m of LN<sub>2</sub> piping serve as a heat shield. Cavities and solenoids are suspended from a common support frame itself suspended from the tank lid. Pre-cool of components is done by delivering cold helium vapour to the bottom of each major component through a supply manifold and 3/16" OD stainless steel tubing internal to the helium reservoir. Magnetic shielding in the form of high  $\mu$  sheet is suspended between the warm wall and the cold shield. Thin diagnostic boxes are positioned at waists in the transverse envelopes between cryomodules.

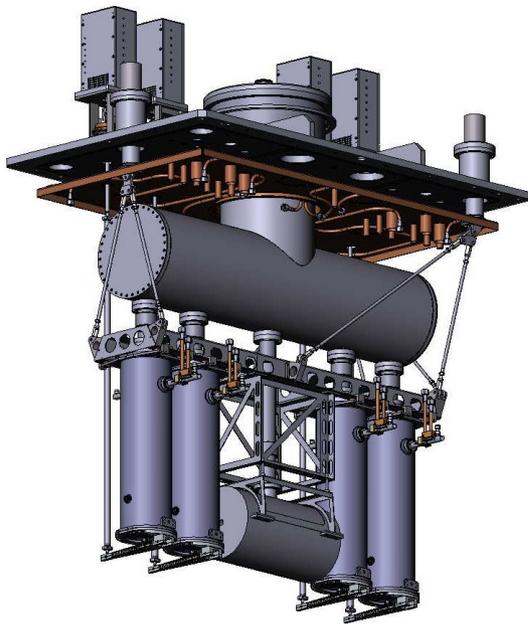


Figure 5: The ISAC-II prototype medium beta cryomodule.

**Solenoids** Focusing in the SC LINAC is provided by 9 Tesla 26 mm diameter bore SC solenoids of lengths 16, 34 and 45 cm corresponding to the low, medium and high beta cryomodules respectively. The solenoids are equipped with bucking coils to actively limit the fringe field in adjacent cavities to less than 0.1 T to prevent reduction in cavity performance. The magnets are mounted in a liquid Helium vessel fed from the common Helium header. An order for five medium beta and two high beta solenoids placed in industry has been delayed as the company has gone into receivership. The prototype magnet was obtained from the company and will be completed and tested at TRIUMF. A contract for the remaining seven magnets has just been let with another supplier.

**Alignment** The cavities must be aligned to within 0.4 mm and the solenoid to 0.2 mm. TRIUMF is developing a stretched wire alignment system based on the TESLA design[4]. Wire position monitors (WPM), each consisting of four striplines are attached to the cavities and solenoid by off-center alignment jigs. A wire running parallel to the beam axis and through the monitors carries an rf signal at 215 MHz. A Bergoz BPM card converts the rf signals from one monitor into DC X and Y signals while a multiplexer with GaAs switches scans through the monitors. A National Instruments ADC and I/O card controls the multiplexer and reads the DC signals. A calibration set-up with XY translation table to raster scan the strip-line monitor with respect to the signal cable is now operational and demonstrates a resolution and reproducibility of  $20\mu\text{m}$ .

### Refrigeration

The ISAC-II refrigeration system is now specified for tender. An order for the first phase will be awarded in Sept. 2003 for commissioning by the end of 2004. A second equivalent order to cover the staged installation of ISAC-II is expected in about three years. Each phase calls for a 500 W class machine. Assuming an active rf load of 8 W/cavity (7 W rf surfaces, 1 W coupling loop) the expected linac load at 4.5 K exclusive of transfer lines is 290 W. The peak liquification required for a cryomodule cool down and fill of duration six hours is  $\sim 5.2$  gm/sec.

### REFERENCES

- [1] R.E. Laxdal, *ISAC-I and ISAC-II at TRIUMF: Achieved Performance and New Construction*, LINAC2002, Korea.
- [2] K. Fong, *et al*, *RF Control System for ISAC II Superconducting Cavities*, Proceedings of the 2003 Particle Accelerator Conference, PAC2003, Portland USA, May 2003, to be published.
- [3] K. Fong, *et al*, *A Mechanical Tuner and RF Drive Line System for the ISAC-II Quarter Wave Superconducting Cavities*, this conference.
- [4] D. Giove, *et al*, *A Wire Position Monitor (WPM) System to Control the Cold Mass Movements Inside the TRF Cryomodule*, PAC 1997, pp. 3657-3659.