THE ISAC-II UPGRADE AT TRIUMF - PROGRESS AND DEVELOPMENTS

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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.

1 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 equiped 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 for 2010. The final energies expected for each stage are summarized in Fig. 2 with and without the inclusion of a secondary stripper before the medium beta section.

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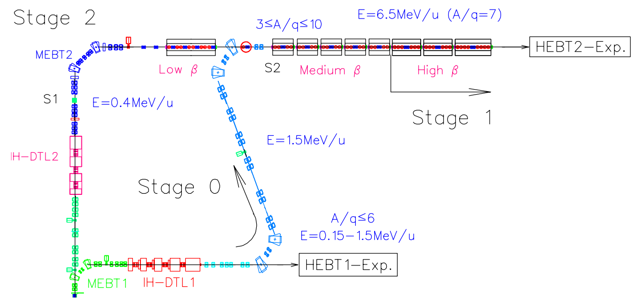

Figure 1: Stages 0, 1 and 2 for the ISAC-II upgrade.

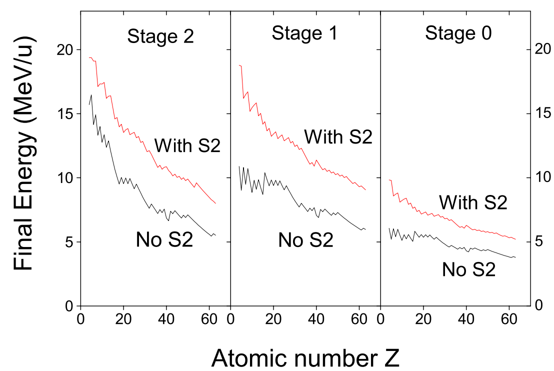

Figure 2: Final ion energy for Stages 0, 1 and 2.

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.

2 BEAM DYNAMICS

Beam dynamics studies with realistic fields were done to optimize the high beta cavity design. Two cavity variants are considered.. One variant has identical transverse dimensions to the medium beta cavity but is designed as a 141 MHz cavity by shortening the overall length. In the other variant the cavity frequency is kept at 106 MHz but the cavity transverse dimensions are scaled to increase the beta from 7.1% to 10.4%. The quadrupole asymmetry in the accelerating fields [2] is somewhat larger in the high frequency case by virtue of the smaller inner conductor. A summary of the beam dynamics calculations is given in Fig. 3. The reduced quadrupole asymmetry in the low frequency cavity results in less asymmetry in the transverse envelope. However the transverse emittance is only marginally better.

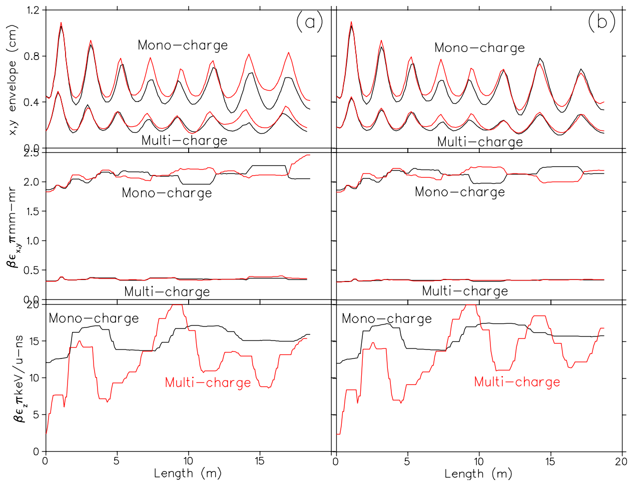

Figure 3: The transverse beam envelopes and the transverse and longitudinal emittances as a function of longitudinal position along the medium and high beta sections for (a) the 140MHz high beta variant and (b) the 106 MHz variant. In each case a single charge state beam with initial emittance of 1.8πmm-mr and 12πkeV/u-ns (ten times the expected emittances) is simulated. The large beam is used to characterize differences in the effective dynamic aperture of the two variants. Also shown is a multi-charge beam ($\Delta Q/Q = \pm 5\%$) with initial emittances of 0.3πmm-mr and 2.πkeV/u-ns.

3 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.

3.1 *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 ± 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 [3] 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 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.

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. 4). The plate is capable of allowing $\pm$20kHz ($\pm$3 mm) of tuning range.

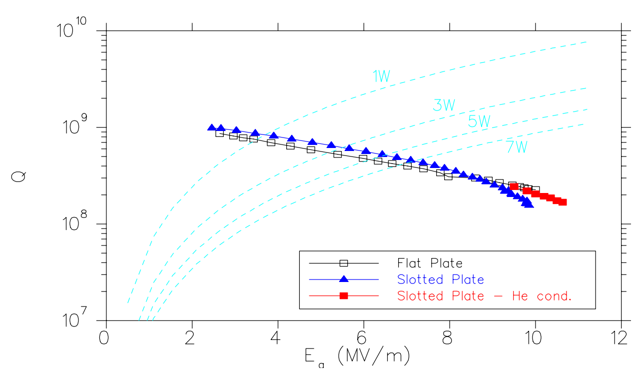

Figure 4: RF cold test results comparing cavity performance with a flat tuner plate and the new slotted plate.

Mechanical Tuner A prototype mechanical tuner[4] 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 $\sim 0.055\mu$m (0.3 Hz). The demonstrated dynamic and coarse range of the tuner are ± 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. The tuner responds accurately to the pressure variation with a resolution better than 0.1μm (0.6 Hz)[4]. The demonstrated response bandwidth is presently limited to 20 Hz by a mechanical resonance.

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 for completion in Aug. 2003. We have taken receipt of an initial series of four of the 7.1% cavities after chemical polishing at CERN. The cavities are being outfitted with stainless steel damper assemblies and pre-cool tubes in preparation for rf tests to begin later this month.

3.2 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 $\simeq$ 36 m of LN2 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 μ sheet is suspended between the warm wall and the cold shield. Thin diagnostic boxes are positioned at waists in the transverse envelopes between cryomodules.

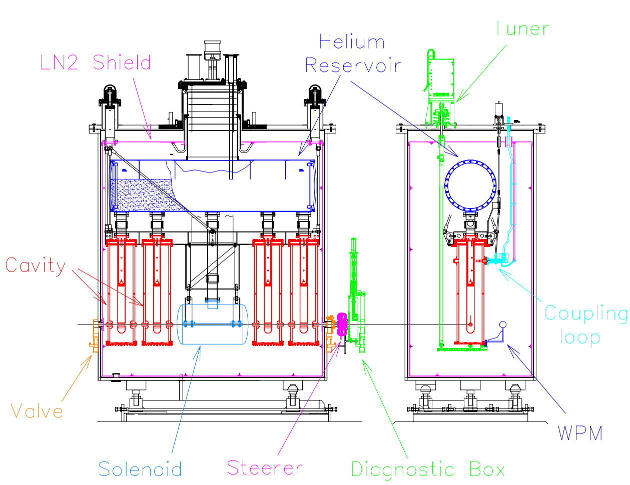

Figure 5: The ISAC-II prototype medium beta cryomodule.

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 equiped 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[5]. 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.

3.3 Charge State Booster

A 14 GHz Phoenix source charge state booster is being assembled on a test stand at TRIUMF. The test stand includes an existing 1^+ ion source, beam-line optics, diagnostics for measuring conversion efficiency and emittance and an analyzing magnet. Development will begin in Sept. and last for one year before the CSB will be installed in the low energy beam line upstream of the RFQ for commissioning and production.

3.4 Refrigeration

The ISAC-II refrigeration system is now specified for tender. An order for the first phase will be awarded in June 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.

4 REFERENCES

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