First cold test of the ISAC-II medium beta cryomodule

Sekachev I., Laxdal R.E., Marshall C., Ries T., Stanford G.,

TRIUMF, 4004 Wesbrook Mall, Vancouver, BC, Canada, V6T 2A3

ISAC-II is an upgrade of the ISAC radioactive beam facility that includes the addition of 43 MV of heavy ion superconducting accelerator. A medium-beta cryomodule comprises four superconducting quarter-wave cavities and one superconducting solenoid magnet. An initial cryomodule has been assembled and cooled with LHe from a supply dewar. This paper will summarize the design of the medium-beta cryomodule and will present the results of the first cold test and alignment.

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. Central to the upgrade is the installation of 43 MV of heavy ion superconducting linac. The superconducting linac is composed of two-gap, bulk niobium, quarter wave RF cavities, for acceleration, and superconducting solenoids, for periodic transverse focusing, housed in several cryomodules and grouped into low, medium and high-beta sections. Each cryomodule has a single vacuum system for thermo-isolation and beam. This demands extreme cleanliness of internal components to avoid superconducting surface contamination. An initial stage to be completed in 2005 includes the installation of the medium-beta section consisting of five cryomodules. An initial cryomodule has been designed and assembled at TRIUMF.

CRYOMODULE ENGINEERING

The medium-beta cryomodule, described elsewhere[1], is a stainless steel vacuum tank containing four superconducting quarter wave RF cavities and one superconducting 9-Tesla focusing solenoid. The superconducting elements are supported on a beam that is suspended from the lid by struts (Figure. 1). The struts are slung from three adjustable points, two upstream and one downstream, that are mounted on a plate that is laterally and for/aft adjustable. There is an independently mounted liquid helium reservoir (120 L inventory) suspended from the lid attached to the superconducting elements by soft bellows. All the superconducting elements are aligned with respect to each other on the support beam and then aligned relative to the vacuum tank beam ports with a measured cold-offset to allow for thermal contraction. The efficiency of cooldown is improved by a manifold and distribution system `spider', connected to the LHe transfer line, that delivers cold gas and liquid to the bottom of each element through 5mm Cu tubing. Once the liquid begins to collect in the reservoir a pre-cool valve on the distribution manifold is opened and LHe flows directly into the reservoir. Except for the niobium cavities the cold mass is predominantly made from 316L stainless steel.

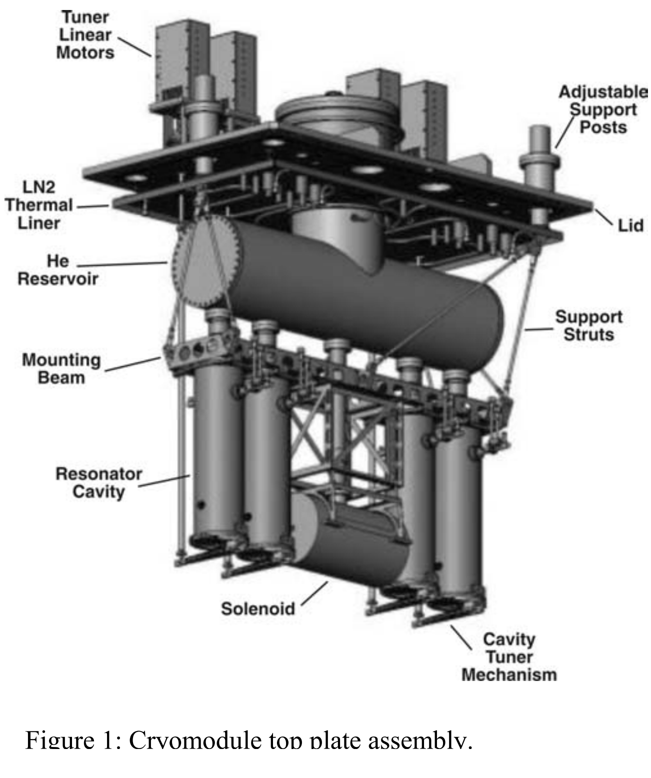


Figure 1: Cryomodule top plate assembly.

The entire cold mass is surrounded by a forced flow, liquid nitrogen cooled, thermal shield. The shield consists of several Cu panels riveted together to form a box with 10mm ID Cu tubing soldered to the panels to form a serial LN2circuit. After soldering the panels are nickel plated. A μ-metal magnetic shield is attached to the inside of the vacuum tank outside the LN2 shield. A single LN2 panel and μ-metal shield suspended from the lid make up the top thermal and magnetic enclosure respectively.

<u>Assembly and Alignment</u>

A wire position monitor (WPM) system[2] is used to provide an off-axis measure of the cavity and solenoid positions during cooldown. WPMs, each consisting of four strip lines, are attached to the cavities and solenoid by an `L'-bracket, positioning them at the horizontal beam plane 0.31-m transverse to the beam direction. A wire running parallel to the beam axis and through the monitors carries an RF signal that is converted to an x-y position. The lid is accurately located to the vacuum tank via a pair of dowels. The beam ports in the vacuum tank are accurately located to these dowels via a transfer fixture. An assembly stand (Figure. 2), which mimics the vacuum tank, is used to assemble all the tank internals to the lid. The top flange is machined flat and dowel pins are used to precisely position the top plate on the stand. The transfer jig is used to transfer the lid reference to a line of sight replicating the reference beam line and the WPM wire line. An outrigger bracket at either end of the stand allows the mounting of telescopes, and end plates are equipped with `dummy' beam flanges and WPM flanges. Both cryomass elements and WPM striplines are prealigned at room temperature to the theoretical line of sights with telescopes and alignment targets fitted in the beam tubes of the cavities, solenoid and striplines.

Figure 2: Top plate assembly in assembly stand.

The cryomodule tank is also outfitted with a pair of optical windows and alignment targets to set up and monitor an external optical reference line with a telescope. As well a pair of optical targets are installed in the upstream and downstream cavities. After the warm alignment in the assembly frame the top assembly is lowered into the vacuum tank, the wire is attached to the end flanges and tensioning device, and the cryomodule is prepared for pumpdown. Optical measurements, taken periodically, serve to check for unexpected differences between the WPM position and the position of the cold mass. During cooldown they provide a calibration of the thermal contraction of the WPM brackets. The cold tests not only establish the integrity of the cryostat and the static load but also determines the required warm offset of each element such that they are aligned at cold temperature. After the initial cooldown the cryomodule is warmed and opened, the elements adjusted to their warm offset position. The tank is then reassembled, recooled and the alignment checked with both WPM and optical targets. The required alignment tolerance is ±400 μm and ±200 μm for the cavities and solenoid respectivly. Once the internal alignment is complete the cryomodule is installed in the accelerator vault and the beam ports are aligned to the theoretical beam centerline. Three target posts on the lid can be characterized in space relative to building benchmarks such that, in future, when the accelerator is operational, a cryomodule can be removed and reinstalled to the same position.

<u>Expected Cooldown Performance</u>

A flow of 6 liquid liters/hour of 100% liquid nitrogen is expected to cooldown the medium-beta cryomodule LN_2 shield in ~24 hours. The bulk of the cold mass will cool by radiation to ~250K. With this flow and assuming 36-m of 10-mm pipe inside the cryomodule, the pressure drop falls from 13.1-kPa while warm to 0.69-kPa while cold. During design it was estimated that the cryomodule would have a static load of 13~W and this number was used to estimate the required refrigerator power. It is estimated that a flow of 100ltr/hr for seven hours would be required to collect liquid.

CRYOMODULE COMMISSIONING

The cryomodule assembly and commissioning tests are conducted in the clean laboratory area in the new ISAC-II building. LN2 for pre-cooling and shield cooling is fed from a transfer line coming from an external tank. Helium is presently fed from local dewars; plans are underway to add a transfer line from the soon to be installed LHe refrigerator[3]. Exhaust gases from the cryomodule are passed through vaporizers and the flow is monitored by gas meters. A local computer records WPM information. Control and data acquisition are done with an EPICS control system. All pertinent signals are logged for future analysis.

Warm measurements

At room temperature and atmosphere the lid is installed, WPM assembled, and bolts tightened to 45 ft-lbs. The bolts are then loosened and the lid lifted off the O-ring by a few mm, so as not to disturb the WPM assembly, then reinstalled. The lifting and tightening are repeated five times and the wpm position coordinates are taken for each. The results are shown in Figure. 3. In all cases the vertical measurements repeat within ±20 μm. The horizontal position changes after the first cycle, `A', as the cavity support frame skews but stays within ±75 μm after this first cycle. The horizontal `walk' may be due to the strut geometry at the downstream end. In this case the two main struts are slung from the same support tower while in the upstream end the two main struts are slung from separate towers.

The vacuum pump down is repeated twice. The final position of the WPM's in both horizontal and vertical planes is repeatable to within 20μm.

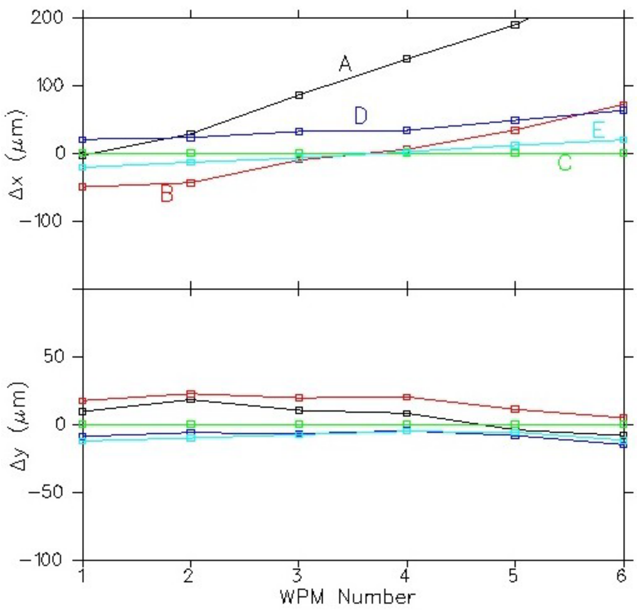


Figure 3: Repeatability of WPM position after repeated (`A' to `E') lifting of lid and torquing down bolts.

Cold Measurements

The cold tests can be grouped into alignment tests and cryogenic tests. The tests include three temperature cycles from room temperature to LN2 temperature and one cooldown to helium temperature.

Alignment: The main goal is to determine the repeatability of the cooldown process and to establish offset values for each cavity and the solenoid to enable warm positioning compatible with alignment at cold temperatures. Cold vertical and horizontal wpm positions are given in Figure. 4 for the four thermal cycles. Due to the different materials involved the solenoid experienced more vertical contraction, with ~4.4mm at LN2 and ~5mm at LHe temperatures while the cavities contracted ~3.3mm at LN2 and 3.8mm at LHe temperatures. The contraction of the cavities was somewhat position dependent with WPM1 and WPM2 shifting vertically about 0.2mm more than WPM5 and WPM6. The vertical contraction at cold tempatures varies somewhat since the temperature of the side shield hence the average strut temperature is not constant. In the horizontal direction things are far less clear. It is expected that the WPM mould move upon cooling since the off-axis stainless steel brackets would contract. However there is a 0.45mm difference between the movement of WPM1 and WPM6, evidence

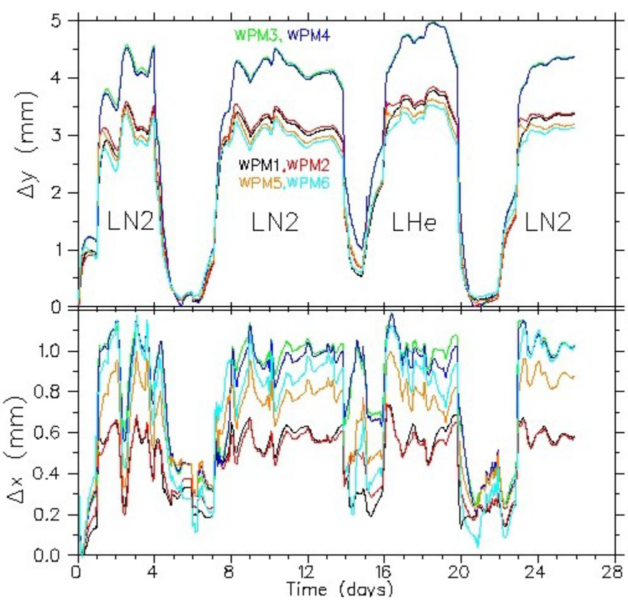


Figure 4: X and Y WPM position history during the four cooldown cycles.

that the cavity support beam is yawing laterally during cooldown. The position of the cold mass is analyzed at three cold LN2 temperatures where the sensors on the cold mass are coincident. The differences in position between cycle 2 and cycle 1 and 3 are summarized in Figure. 5. The positions are repeatable to within ±50 µm vertically and ±100µm horizontally. Again the horizontal position of the downstream end is found to be less stable than the upstream end. The optical target psotions are recorded periodically during the cold cycling. A comparison between the optical targets and the visual targets gives the calibration for WPM position relative to the beam ports. The differences are due to the different contraction of the bracket material and the niobium cavity. A change of pressure in the helium space inflates the bellows resulting in a net force on the cavity support frame yielding a measured deflection of 30µm/100Torr pressure variation. The same pressure variation also caused a side load on the support frame skewing the frame by 10µm/100Torr.

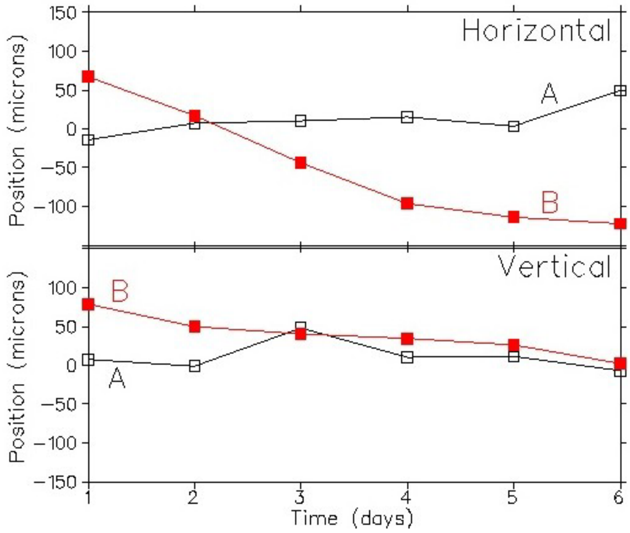


Figure 5: Comparison of WPM positions during three LN2 cold periods with second cycle used as reference.

Cryogenic Tests

The LHe fill was preceded by an LN2 fill. The LN2 is boiled off by spoiling the vacuum with 1Torr helium plus internal cold mass heaters. The helium space was pumped to determine that no LN2 remained then the vacuum was restored before the fill. The cold-mass began the fill at an average temperature of 210K. Initially three 100L dewars were used to start liquid collection in the cavities after five hours. At this point the average cavity temperature reached 20K. The fill shows clearly that the distribution `spider' effectively distributes the helium to the bottom of all cold masses. A further 250LHe is required to fill the magnet. In all 1400LHe is consumed over a period of three days to fully thermalize the cryomodule. The final static load on the helium, after thermalization, as measured from the gas boil-off is 10W (Figure. 6). The LN2 flow required to keep the side shield less than 100K is determined to be ~5ltr/hr matching design estimates.

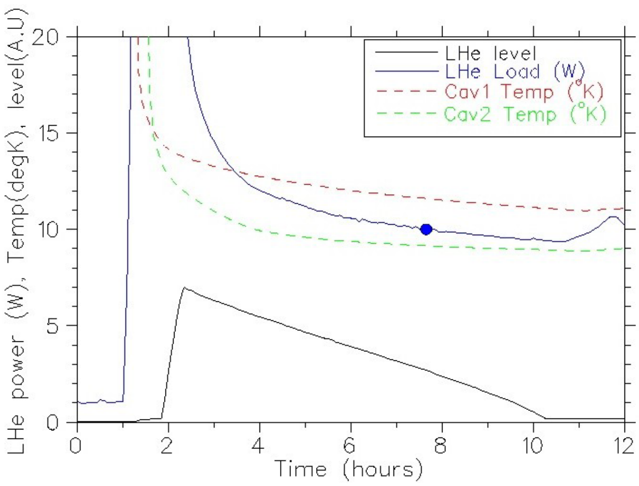


Figure 6: LHe level (A.U.)and static load (W) measured from gas boil off. Also shown are temperature of top flange of cavity 1 and 2 showing the thermalization.

CONCLUSIONS

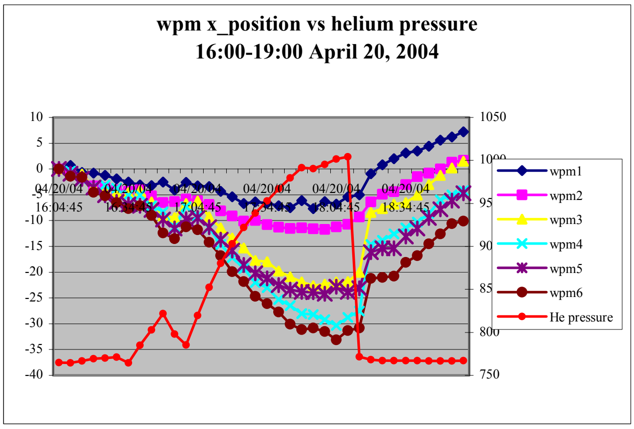
The first medium beta cryomodule cold test has been a total success. The distribution `spider' distributes the cold gas evenly to the bottom of the cold mass. The static load and required LN2 flow are 10W and 5ltr/hr respectively, within design estimates. A WPM six monitor system developed at TRIUMF is now operational. The system monitors continuously the position of the structure during cold cycling. The three point mount system produces a slight temperature dependent skew in the cavity support frame.

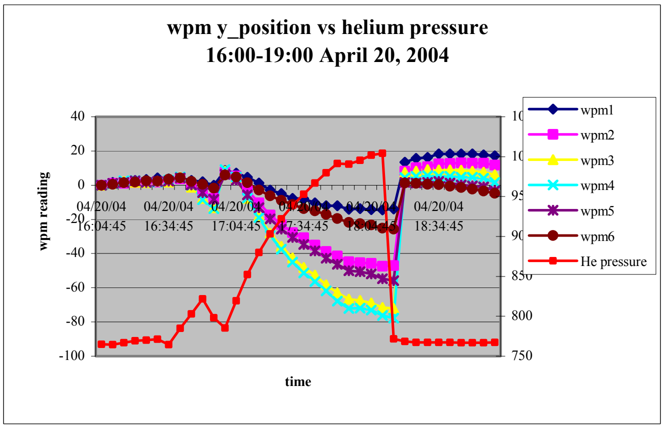
REFERENCES

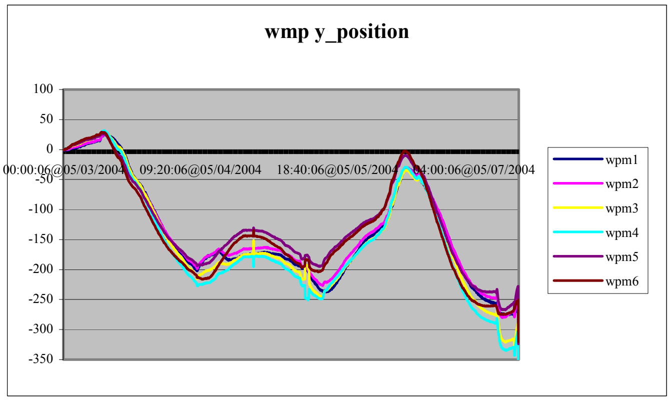
[1] G. Stanford, et al, Design of the Medium Beta Cryomodule for the ISAC-II Superconducting Heavy Ion Linac, Alaska Cryogenic Conference

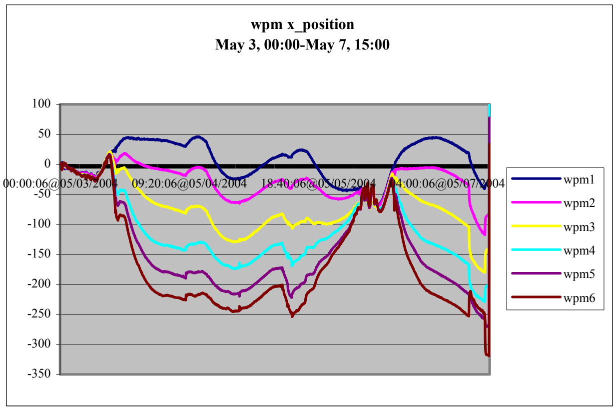
[2] W. Rawnsley, et al, Alignment of the ISAC-II Medium Beta Cryomodule with a Wire Monitoring System, this conference.

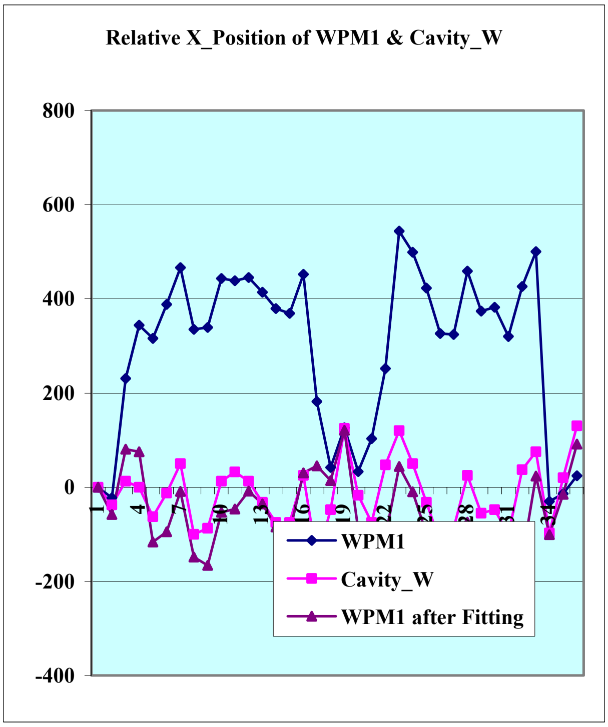
[3] I. Sekachev, et al, Status of the ISAC-II Cryogenic System, this conference.

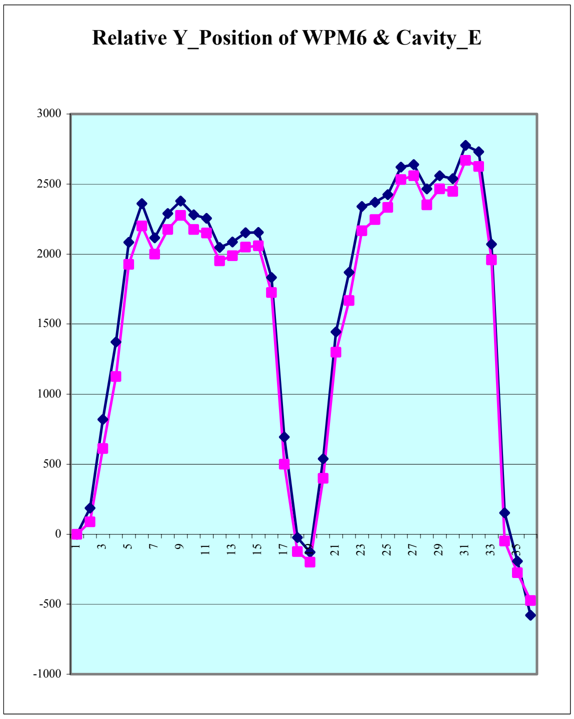

wpm x_position vs helium pressure
16:00-19:00 April 20, 2004
wpm1
wpm2
wpm3
wpm4
wpm5
wpm6
He pressure


wpm y_position vs helium pressure
16:00-19:00 April 20, 2004
wpm reading
time
wpm1
wpm2
wpm3
wpm4
wpm5
wpm6
He pressure


wmp y_position
wpm1
wpm2
wpm3
wpm4
wpm5
wpm6


wpm x_position
May 3, 00:00-May 7, 15:00
wpm1
wpm2
wpm3
wpm4
wpm5
wpm6


Relative X_Position of WPM1 & Cavity_W
WPM1
Cavity_W
WPM1 after Fitting


Relative Y_Position of WPM6 & Cavity_E