ENGINEERING AND CRYOGENIC TESTING OF THE ISAC-II MEDIUM BETA CRYOMODULE

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Abstract

The medium beta section of the ISAC-II Heavy Ion Accelerator consists of five cryomodules each containing four quarter wave bulk niobium resonators and one superconducting solenoid. A prototype cryomodule has been designed and assembled at TRIUMF. This paper describes the system engineering, alignment procedures and test results.

INTRODUCTION

The ISAC-II[1], superconducting linac is composed of two-gap, bulk niobium, quarter wave RF cavities, for acceleration, and superconducting solenoids (9 T), 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 and precludes the use of volatile lubricants or flux as well as particulate generators 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[2] has been designed and assembled at TRIUMF.

CRYOMODULE ENGINEERING

The stainless steel vacuum tank has dimensions $\sim 2 \times 2 \times 1$m. The superconducting elements are supported on a beam that is suspended from the lid by struts (Fig. 1). The struts are slung from three support points, two upstream and one downstream, that are laterally and vertically adjustable. There is an independently mounted liquid helium reservoir (120ℓ inventory) suspended from the lid attached to the superconducting elements by soft bellows. Except for the niobium cavities the cold mass is predominantly made from 316L stainless steel. 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 5 mm 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.

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 10 mm ID Cu tubing soldered to the panels to form a serial LN2 circuit. After soldering the panels are nickel plated to improve emissivity. A μ-metal magnetic shield, consisting of 1 mm Conetic panels 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.

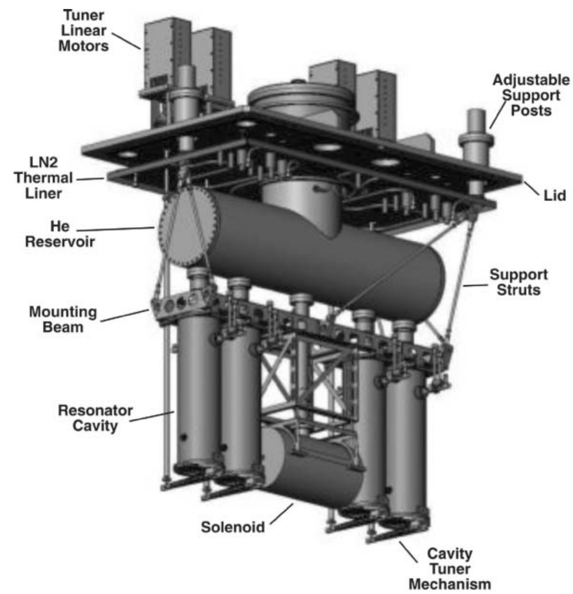

Figure 1: Cryomodule top plate assembly.

Alignment During Assembly and Installation

An assembly stand (Fig.2) is used to assemble the tank internals to the lid. The stand mimics the vacuum tank and uses the same lid location dowel arrangement. The line of sight (LOS) location of the beam and wire position monitor (WPM) ports on the tank are transferred to the adjustable end plates on the assembly stand via a transfer fixture and optical telescope. The tank internals are aligned with respect to the LOS using optical targets in the beam ports. The WPM alignment monitors are aligned with respect to the line of wire (LOW) also with optical targets.

The WPM system[3] provides an off-axis measure of the cavity and solenoid positions during cooldown. The monitors, each consisting of four striplines, are attached to the cavities and solenoid by brackets that position them 0.31 m horizontally from the beam axis. A wire running parallel to the beam axis and through the monitors carries an rf signal that is measured by the striplines and is converted to an x-y position. 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. Optical targets are installed in each cavity and in the upstream and downstream ends of the solenoid. Optical measurements, taken periodically, serve to check for

Figure 2: Top plate assembly in assembly stand.

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 solenoid is required to be centered on the beam axis while the cavities are aligned on the horizontal axis but 750μm below the vertical beam axis. The required alignment tolerance is $\pm$400μm and $\pm$200μm for the cavities and solenoid respectively. 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.

CRYOMODULE COMMISSIONING

The cryomodule assembly and commissioning tests are conducted in the clean laboratory area in the new ISAC-II building. LN2 for 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). 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.

Warm measurements

To accurately predict final cold mass position it is necessary to measure the effect or repeatability of initial lid positioning, vacuum pumpdown, helium space pressure and thermal contraction. Lid positioning studies involve loosening the top bolts, lifting the lid off the o-ring, repositioning the lid and torquing the lid bolts. For five cycles the vertical measurements repeat within $\pm$20μm. The horizontal position skewed after the first cycle but repeated within $\pm$75μm thereafter hence the location of the lid to the tank via the dowel pair is adequate. It is assumed that built in stresses were relieved during the first cycle. During repeated vacuum pumpdowns the position of the WPM's in both horizontal and vertical planes was repeatable to within $\pm$20μm.

Cold Measurements

The cryomodule has undergone two cold tests. The first established the cryogenic and alignment performance and the second characterized the rf and solenoid performance as well as checking the accuracy of alignment shimming. The initial test includes three temperature cycles from room temperature to LN2 temperature and one cooldown to helium temperature. The second test includes one helium and one LN2 cycle.

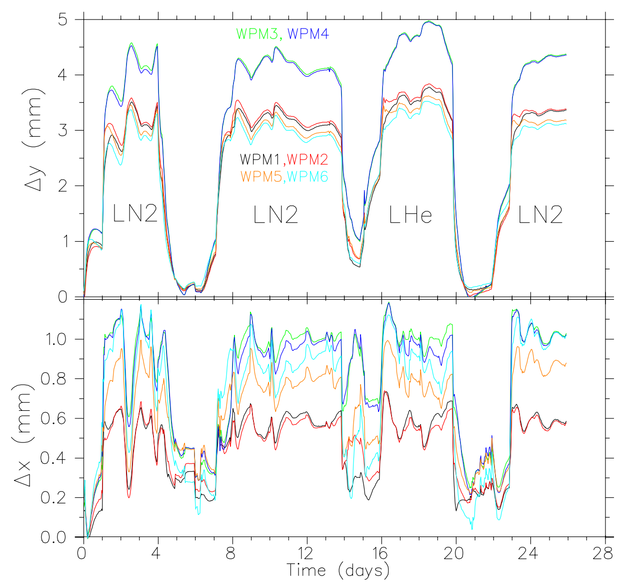

Figure 3: Vertical and horizontal wpm positions for three LN2 cycles and one LHe cycle.

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. Vertical and horizontal wpm positions are given in Fig. 3 for the four thermal cycles during the first cold test. Due to the different materials involved the solenoid experiences more vertical contraction, with $\sim$4.4 mm at LN2 and $\sim$5 mm at LHe temperatures while the cavities contracted $\sim$3.3 mm at LN2 and $\sim$3.8 mm at LHe temperatures. In the horizontal direction there is a 0.45 mm difference between the movement of WPM1 and WPM6, evidence that the cavity support beam is yawing laterally during cooldown. 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 causes a side load on the support frame skewing the frame by 10μm/100Torr.

The position of the cold mass is analyzed at three cold LN2 temperatures. The differences in position between cycle 2 and cycle 1 and 3 are summarized in Fig. 4. The positions are repeatable to within $\pm 50\mu$m vertically and $\pm 100\mu$m horizontally. The horizontal position of the downstream end is found to be less stable than the upstream end since the two main struts at the downstream end are slung from the same support tower while in the upstream end the two main struts are slung from separate towers.

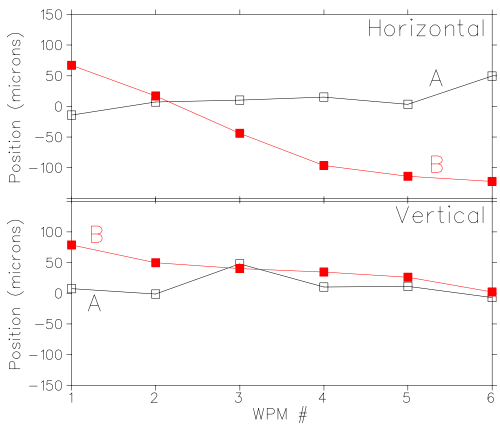

Figure 4: Relative WPM positions for three LN2 cooldown cycles.

The cryomodule is warmed, opened and the elements adjusted to the warm offset position established during the initial cold test. Alignment correction is achieved horizontally via threaded adjusters and vertically by the machining of support shims. The tank is then reassembled, recooled and the alignment checked with both WPM and optical targets. The solenoid is warm aligned on the LOS and during cooldown the adjusters on the three external support posts are used to position the cold solenoid back on the LOS. The warm off-set position and final cold position with respect to the specified positions of the six optical targets are given in Fig. 5. The final position in the vertical plane is within $\pm 150\mu$m. However, a temperature dependent skew in the horizontal position of the solenoid was noted during the cooldown. The surprising result is that the skew is not apparent in the WPM data leading us to believe that the solenoid bore tube is somehow warping during cooldown. This result was also observed during a second LN2 thermal cycle. Further investigations are required.

Cryogenic tests: During the commissioning tests the cold mass is pre-cooled with LN2. The helium space is pumped and purged prior to helium transfer. During helium transfer the distribution 'spider' effectively distributes the helium to the bottom of all cold masses. Due to the difference in mass and geometry the cavities cool at a rate of 70°K/hr while the solenoid cools at 20°K/hr for a transfer rate of $\sim 80\ell$/hr. We are presently designing a new three position manifold valve that can force cold gas preferentially to the solenoid.

In the first test the final static load on the helium, after

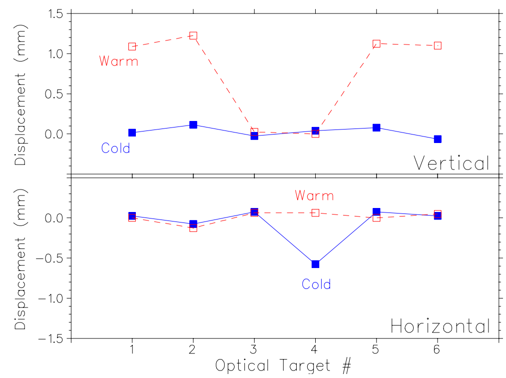

Figure 5: Measured positions of the six optical targets relative to their specified positions for warm and cold conditions.

thermalization, as measured from the gas boil-off is 11 W. In the second test after adding rf cables, tuner actuators and solenoid leads the static load rose to 16 W. This can be compared to the design estimate of 13 W. Removal of the wpm cabling will reduce the static load. However we are presently reviewing the equipment added during the second test with the aim to further reduce the final load. The LN2 flow required to keep the side shield less than 100°K is measured to be $\sim 5\ell$/hr matching design estimates.

Mechanical studies:The characterization of the mechanical modes is useful to diagnose the source of spectral noise in the rf error signal during rf cold tests. The mechanical modes of the cryomodule assembly are measured in two ways. In the first an accelerometer is attached to a cavity to measure transvere motion. Various parts of the assembly are struck with an impulse and the induced signal is passed to a spectrum analyzer. In the second the raw wpm signal is passed to the spectrum analyzer and the assembly is excited by stepping a mechanical tuner[4] attached to the bottom of one of the cavities through a long actuator rod. The studies give similar results except that the wpm signal also contains the wire resonant frequency of 43 Hz. Simulations predict the lowest frequency mechanical mode of the cryomodule assembly to be 14.3 Hz. Measurements do confirm the mode at 14 Hz but also clearly show a mode at 6 Hz. It is thought that the lower mode is due to a small backlash in the support strut spherical joint couplings that 'loosen' the mechanical system.

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