Alignment of the ISAC-II Medium Beta Cryomodule with a Wire Monitoring System

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TRIUMF is developing ISAC-II, a superconducting (SC) linac. It will comprise 9 cryomodules with a total of 48 niobium cavities and 12 SC solenoids. They must remain aligned at liquid He temperatures: cavities to ±400 µm and solenoids to ±200 µm after a vertical contraction of ~4 mm. A wire position monitor (WPM) system based on a TESLA design measures the signals induced in stripline pickups by a 215 MHz signal carried by a position reference wire. The sensors, one per cavity and two per solenoid, monitor their motion during pre-alignment, pumping and cool down. System accuracy is ~7 µm.

INTRODUCTION

TRIUMF is now constructing an extension to the ISAC facility, ISAC II, to permit acceleration of radioactive ion beams up to energies of at least 6.5 MeV/u for masses up to 150. The proposed acceleration scheme will 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 will 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. A total of 48 cavities and 12 solenoids will be used. The center line of each cavity must be aligned to within ±400 µm of the true beamline centre while that of the solenoid must be within ±200 µm .

We will discuss the system that has been designed to monitor changes in the alignment of the cavities and solenoids during pump out and cool down. The system has been tested in the first of five medium beta cryomodules, each containing four cavities and a single solenoid, see Figure 1 [1].

METHOD

Wire Position Monitors (WPM's)

A stretched wire alignment system based on a TESLA Test Facility system has been developed at TRIUMF [2,3]. Six WPM's, one per cavity and two on the solenoid, are positioned along a wire displaced 30.48 mm horizontally from the beam axis to measure lateral displacements. The wire, stretched between the tank walls, provides a position reference and carries a 215 MHz rf signal. The WPM's are supported from the cold masses by stainless steel brackets.

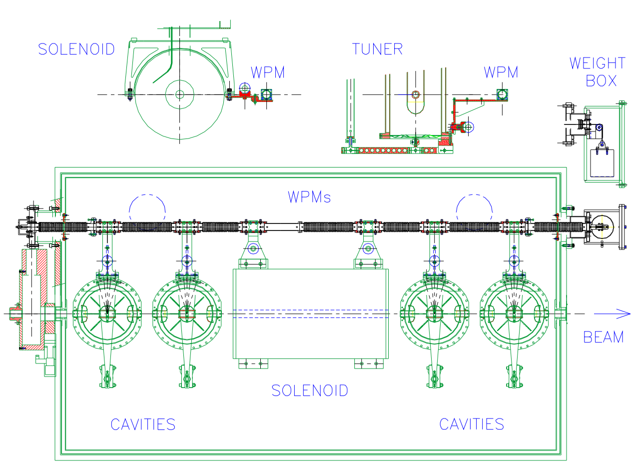

Figure 1 A plan view of a medium beta cryomodule and cross-sections of the wire weight box and WPM mounting brackets.

Each WPM is similar to a beam position monitor, Figure 2. It contains four Cu plated Al antennas supported by SMA jacks. The upstream ports are connected to the readout electronics which measure the signal amplitudes while the downstream ports are terminated by a 50 Ω loads. The striplines are 0.254 mm wide, and 61 mm long. Their heights are set to give 50 Ω impedance using a network analyzer in time domain reflectometry (TDR) mode. The Au plated brass Johnson SMA jacks use Teflon insulation. The jacks were found to contract by 50 μm overall when cooled with LN_2 but this can be accounted for by the brass alone. The thermal expansion coefficient of Teflon is six times that of brass for this temperature change, however, the internal geometry of the jack appears to prevent this from being a problem. The electronics measures differentially, cancelling common mode contraction effects to first order. Bench tests were performed on a single WPM using rf applied to a rod rigidly supported 3 mm off centre by end caps. The apparatus was cooled using LN_2 in a small cryostat in air and an average change in readings of 16 μm was measured. Some of the change may have been due to condensation or temperature differentials.

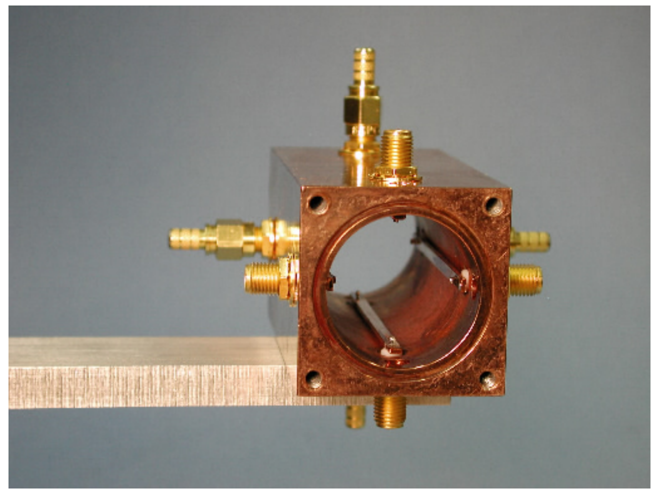

Figure 2 The stripline pickups of a WPM are spaced at 90° in the 28 mm bore and supported by SMA jacks.

Position Reference Wire

The 0.5 mm diameter bronze-Cu wire has a sag of 0.162 mm over a length of 2 m with a stretching load of 4.55 Kg provided by a pulley and weight in the vacuum. The wire passes through pin holes in dielectric disks at each end to define its path. It runs inside thin walled stainless steel bellows between monitors in order to form a coaxial transmission line. The corrugations of the bellows create a slow wave structure. The ends of each bellows are welded to square plates which are screwed to the monitors. Pump out holes are placed symmetrically around the circumferences. Two special bellows pieces carry the rf signal through the tank ports. They pass through the magnetic shield and have a floating flange in the middle for thermal contact with the LN_2 shield.

A TDR measurement indicated a wire impedance of 251 Ω. The sum of the signal strength from each WPM varies by about ±7% along the wire indicating little loss. The rf signal source is not matched to the wire impedance. Instead the rf passes through 10 dB of attenuators and a vacuum feedthru on the weight box and is connected to the wire by a jumper. The far end of the wire passes through a vacuum feedthru and is terminated by a 220 Ω resistor. This provides a directivity of 7 dB at the end WPM and is a measure of the quality of the termination. We wish to minimize the reflection as it provides a contribution to the WPM signal strength which varies with the WPM load resistance. The DC resistance of the Pasternack loads varied by 0.07 Ω on average when cooled with LN_2.

Cables

The signals are carried to the tank lid SMA feedthrus by 2.28 m long RG-303 cables with 0.5 dB loss. The cables use FEP and Teflon insulation and are vacuum compatible. Their impedance was found to decrease by 1.7 Ω when cooled with LN_2. 18.3 m long RG-223 double shielded cables with an attenuation of 3.5 dB carry the signals to the electronics.

Data Acquisition

The response of the stripline signals for a centred wire was measured to be about -40.5 dB using a network analyzer. An accidental short of the wire to a stripline would decrease the loss to only -3.6 dB. Attenuators at the amplifier output insure that fault

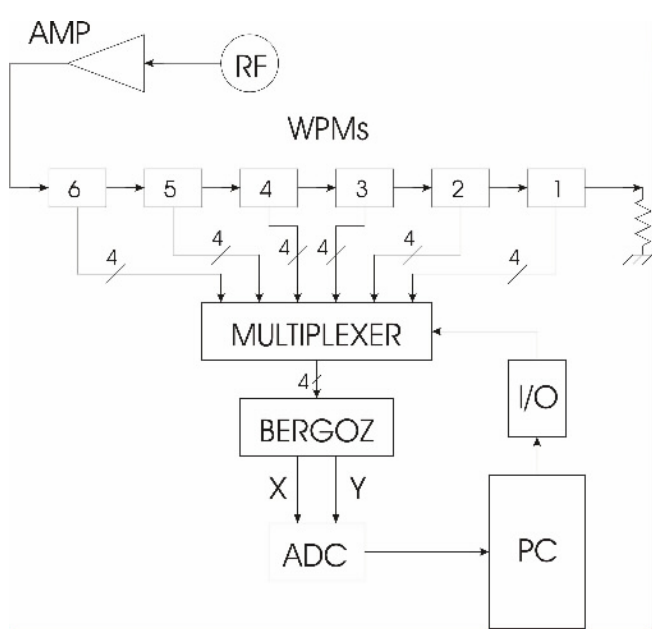

Figure 3 A block diagram of the data acquisition electronics.

levels cannot exceed the maximum input to the Bergoz card of 24 dBm and that the SWR remains less than 2:1 to protect the amplifier.

The TRIUMF built rf multiplexer uses M/A-Com SW-221 GaAs switches yielding greater than 60 dB isolation and 1.2 dB insertion loss, see Figure 3. Each of the four channels (l,r,d,u) is housed in a single width NIM module and selects one of the WPM's. The other inputs are switched to 50 Ω loads. The Bergoz Instrumentation card provides a single detector front end and is based on a four channel rf multiplexer, a down converter, a single AGC IF amplifier and a homodyne amplitude detector [4]. The card takes care of the rf to dc conversion and is insensitive to rf phase. The electrical noise specification is given as 8.9×10^{-6} diameter/√Hz for signal levels above -50 dBm. Given our 28 mm diameter and a bandwidth of 10 Hz the electronics would contribute a noise to the position measurement of only 0.8 µm RMS. A National Instruments PCI bus 16 bit ADC card reads the dc signals and a digital I/O card controls the multiplexer. The PC uses Windows XP and runs a LabVIEW program written by the SIDeA Corporation of Milan.

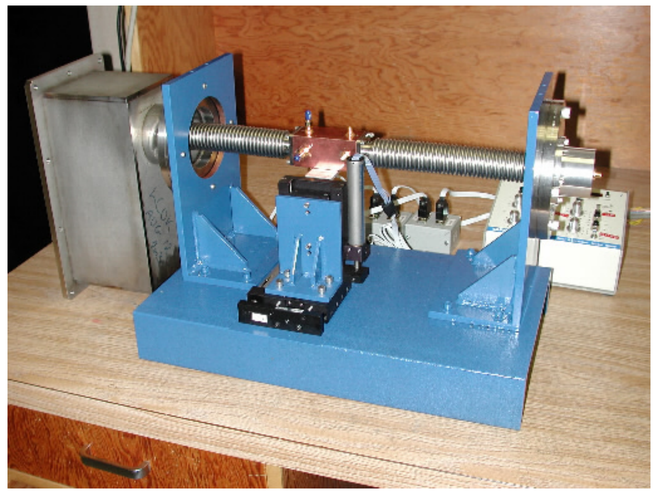

Figure 4 The calibration stand with the weight box on the left, a WPM, bellows and the Oriel interface behind.

Calibration

The WPM's are non-linear and must be calibrated. A pair of Oriel translator stages mounted a right angles are used to move a WPM about a stretched wire, see Figure 4. The servo motor units contain optical encoders with a resolution of 0.1 mm. The weight box and flanges from the cryomodule are used and the scan is computer controlled. A raster scan with 0.2 mm steps over a range of ±6 mm requires about 2 hours. A 2D, third order polynomial curve fit is used to reduce the data to a set of 20 polynomial coefficients. Beyond ±4.8 mm the electronics sharply compresses the response and though still useable, these points were not included in the curve fits. A fitting error of better than 20 µm was achieved over most of the ±4.8 mm range, exceeding it only near the ends of the range.

RESULTS

Preparation for Alignment Tests

The WPM system was installed in the cryomodule for alignment measurements during March and April of this year, Figure 5. All accelerator elements in the cryomodule are suspended from a support frame that in turn is suspended from the cryomodule lid with stainless steel struts. The cryomodule lid is installed in an assembly frame that replicates the cryomodule vacuum tank. The assembly frame doubles as an alignment stand. The top flange is machined flat and dowel pins are used to precisely position the top plate on the stand. An alignment jig is used to transfer the lid reference to a line of sight replicating the reference beam line and the WPM wire line. End plates on the assembly frame are fastened to replicate the vacuum tank beam port and WPM flanges. Both cryomass elements and WPM striplines are pre-aligned at room temperature to the theoretical line of sights with telescopes and alignment targets fitted in the beam tubes of the cavities and solenoid.

Figure 5 The cryomodule components in the assembly stand. The WPM system is in the foreground.

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. 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 transferred to the vacuum tank, the wire is attached to the end flanges and tensioning device and the cryomodule is prepared for pump down. Optical measurements are taken periodically. They serve to check for unexpected differences between the WPM position and the position of the cold mass. During cool down they provide a calibration of the thermal contraction of the WPM brackets.

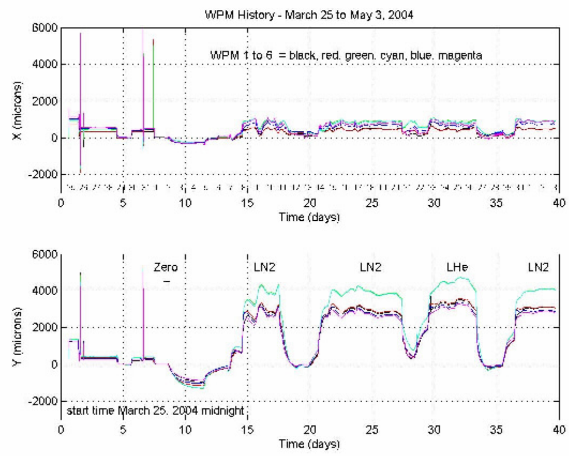

Figure 6 A history of the WPM readings over four temperature cycles.

Measurements

The WPM is useful for both warm and cold studies. Initially the repeatability of the lid bolt up procedure was investigated. The lid was bolted down then unbolted and lifted by a few mm before being bolted down again. This was repeated several times to get an idea of the repeatability of the lid positioning, Warm studies also include the effect on alignment of the tank pump down and the repeatability of the pump down.

The cold tests included three temperature cycles from room temperature to LN_2 temperature and one cool down to He temperature. The main goal is to look at repeatability of the cool down process and to establish cold offset values for each cavity and the solenoid to facilitate warm alignment at initial positions compatible with alignment at cold temperatures. A record of the cold cycle data is given for horizontal and vertical data over several weeks in Figure 6. The cavities contracted about 3 mm while the solenoid position contracted about 4 mm during the test. The position of the cold mass during the three LN_2 cycles proved to be repeatable to within 80 μm vertically and 120 μm horizontally. The graph of the relative position of the WPM's during the cold cycle is shown in Figure 7. A comparison between the optical targets and the visual targets gives the calibration for WPM position relative to the beam ports.

CONCLUSIONS

A WPM six monitor system has been developed at TRIUMF and is now operational on the first ISAC-II medium beta cryomodule. The device is giving a wealth of information over and above the data collected with the installed optical targets. The use of optical targets involves personnel and the readings can be taken only periodically. Conversely the WPM data is monitored continuously providing detailed data that is extremely valuable to help characterize a new structure.

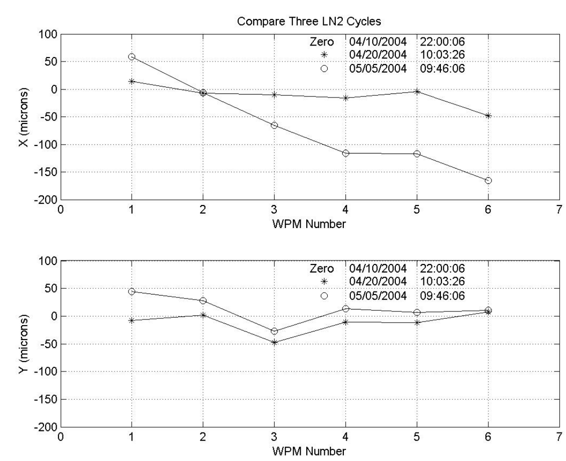

Figure 7 A comparison of the positions at the lowest temperatures achieved during three LN_2 cold cycles.

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