A WIRE POSITION MONITOR SYSTEM FOR THE ISAC-II CRYOMODULE COMPONENTS ALIGNMENT

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Abstract

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 has been developed, built, and tested with a prototype cryomodule. The system is based on the measurement of signals induced in pickups by a 215 MHz signal carried by a wire through the WPMs. The wire is stretched between the warm tank walls parallel to the beam axis providing a position reference. The sensors, one per cavity and two per solenoid, are attached to the cold elements to monitor their motion during pre-alignment, pumping and cool down. A WPM consists of four 50 Ω striplines spaced 90° apart. A GaAs multiplexer scans the WPMs and a Bergoz card converts the rf signals to dc X and Y voltages. National Instruments I/O cards read the dc signals. The data acquisition is based on a PC running LabVIEW. System accuracy is ~7 µm. The paper describes system design, WPM calibration and test results.

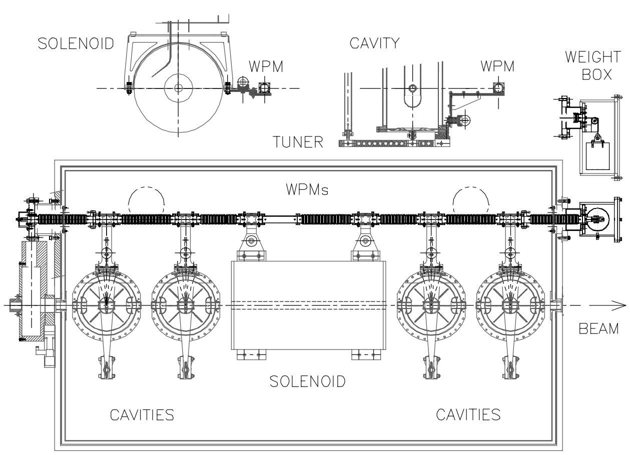

Figure 1: A plan view of a medium beta cryomodule and cross-sections of the wire weight box and WPM mounting brackets.

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

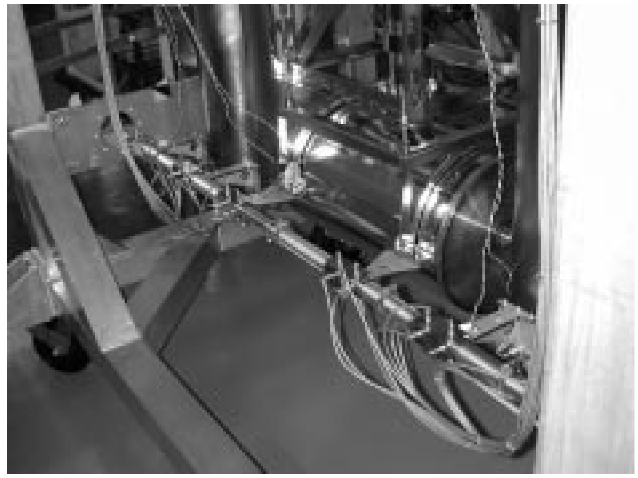

Figure 2: The WPMs and bellows form a coaxial structure. The stripline signals are brought out by 24 rf cables.

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 SC linac designed to accelerate ions of $A/q \leq 7$ to the final energy. The SC linac will be composed of two-gap, bulk niobium quarter wave rf cavities for acceleration and SC 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 those of the solenoids 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, figure 1 [1,2,3].

MEASUREMENT SYSTEM

WPMs

A stretched wire alignment system based on a TESLA Test Facility system has been developed at TRIUMF [4,5]. Six WPMs, 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 WPMs are supported from the cold masses by stainless steel brackets, figure 2.

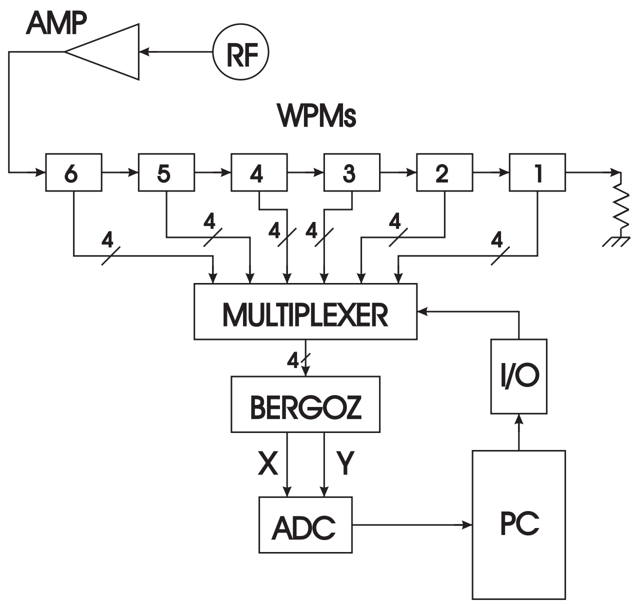

Figure 3: A block diagram of the data acquisition electronics.

Each WPM is similar to a beam position monitor. It contains four Cu plated Al antennas supported by SMA jacks. The downstream ports are connected to the readout electronics which measure the signal amplitudes while the upstream ports are terminated by 50 Ω loads. The striplines are 0.254 mm wide and 61 mm long in a housing with a 28 mm bore. Their heights are set to give 50 Ω impedance using a network analyzer in time domain reflectometry (TDR) mode. 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, however.

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 tensioning load of 4.55 kg provided by a pulley and a 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 flexible 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.

A TDR measurement indicated a wire impedance of 251 Ω. The sum of the signal strengths 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 feedthrough on the weight box and is connected to the wire by a jumper. The far end of the wire passes through a vacuum feedthrough and is terminated by a 220 Ω resistor. This provides a directivity of 7 dB at the end WPM which is a measure of the quality of the termination. We wish to minimize the reflection as it provides a contribution to the stripline signal strengths which varies with their load resistances.

Cables

The signals are carried to the tank lid SMA feedthroughs by 2.28 m long RG-303 cables. They have FEP and Teflon insulation but are not ideal as their centre conductors are silver plated copper clad steel. 18.3 m long RG-223 double shielded cables carry the signals to the electronics. The total cable loss is 4 dB.

Electronics

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, figure 3. Each of the four channels (l,r,d,u) is housed in a single width NIM module which selects one of the WPMs. The unselected inputs are switched to 50 Ω loads. The Bergoz Instrumentation BPM-mux card is based on a four channel rf multiplexer, a down converter, a single AGC IF amplifier and a homodyne amplitude detector [6]. The card takes care of the rf to dc conversion and is insensitive to rf phase. With our bore and a bandwidth of 10 Hz the Bergoz card contributes 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. We record the positions only once every 20 s and allow a long settling time of 1 s after selecting WPMs. A Channel Access server is being implemented in the PC to provide an interface to the EPICS control system data archiver.

Calibration

The WPMs are non-linear and must be individually calibrated along with their rf cable sets. A pair of Oriel

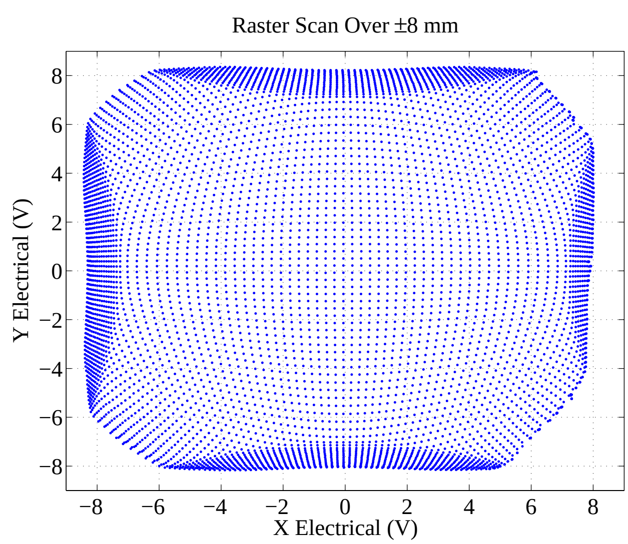

Figure 4: The X and Y voltages from the Bergoz unit are plotted for a calibration raster scan.

translator stages mounted at right angles are used to move a WPM about a stretched wire. The servo motor units contain optical encoders with a resolution of 0.1 µm. 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 ±8 mm is shown in figure 4. 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. The overall WPM system accuracy is limited by the precision of the translators, the Bergoz card and the ADC. We estimate it to be 7 µm or less.

RESULTS

Comparison with Optical Measurement

The cryomodule tank was fitted with a pair of optical windows to allow sighting along the beam axis with a telescope. A pair of optical targets was installed in the upstream and downstream cavities. Optical measurements were taken periodically to check for unexpected differences between the WPM position and the position of the cold mass, figure 5. They also provided a calibration of the thermal contraction of the WPM brackets.

Vibration Studies

The WPM system was used to measure mechanical vibrations. The X and Y signals from the Bergoz card were taken to an HP 35665A analyzer. The Bergoz unit completes a sampling of its four inputs at a 2 kHz rate. For small input level changes that do not cause large AGC swings, the bandwidth is the Nyquist limit of 1 kHz. The tuners were used to shake the cavities with a step function, figure 6. The predominant resonance near 6 Hz

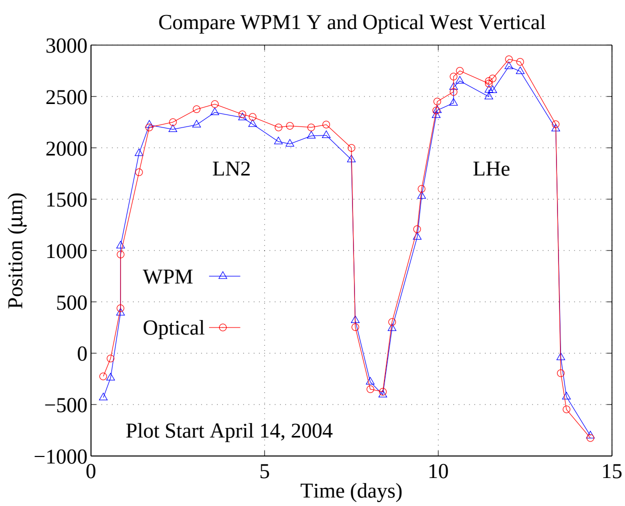

Figure 5: A comparison of the WPM measurements with optical measurements during two cool downs.

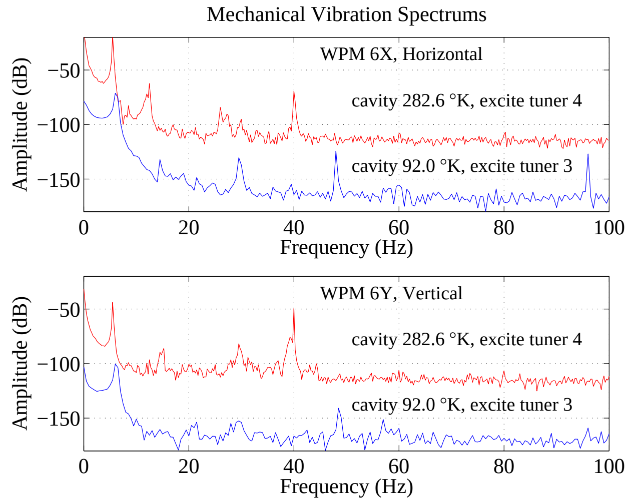

Figure 6: The mechanical vibration spectrum of the cryomodule assembly. The warm spectrums were moved up 60 dB w.r.t. the cool spectrums for clarity.

corresponds to a mainly horizontal movement of the structure with the largest movement being at the downstream end where there is a single support from the tank lid rather than two as at the upstream end. The resonance frequencies increase as the cavity temperatures decrease. The background vibration noise measured during a cool down was less than 7 µm rms.

CONCLUSIONS

The WPM system has advantages over the optical method as it records continuously and does not require personnel to take the readings. It has a high bandwidth and resolution which allow measurement of vibrations.

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