Short description of the SLAC rotating coil system used to measure the CIEMAT-made prototype ILC linac quadrupole

Cherrill Spencer, SLAC, reporting on system developed over several years by Scott Anderson, Dave Jensen, Zack Wolf and herself.

Need to characterize any prototype ILC superconducting quads, especially magnetic center behavior: develop measurement set-up

- Over past several decades SLAC Magnetic Measurement Group (MMG) has developed accurate and precise quadrupole magnet measurement systems based on rotating G10 rods in which multiple sets of thin wires are wound: measuring coils placed in quad's aperture in which voltages are induced, read out & processed to measure integrated strength & multipoles
- Since 2001 MMG have further developed this rotating coil technique so as to measure relative magnetic center change to a ~0.02 micron uncertainty, to qualify quadrupole magnets for use in "Beam Based Alignment" in the main linac of a linear collider
- Magnetic center measurements are sensitive to coil vibration & rotating part wear and environmental effects: temperature and relative humidity and support vibration
- MMG evolved their apparatus to minimize mechanical noise and create environmental isolation
- Described in SLAC-PUB- 11473 by Cherrill M. Spencer et al (2005)

Custom made rotating "coil" for the ILC main linac's superconducting quads with multiple set of windings allowing quad strength, harmonics and magnetic center to all be precisely measured

7 precisely placed grooves carry 6 sets of windings

Coils hand-wound from AWG 36 Litz wire in machined grooves in G10 form, 19 turns each set

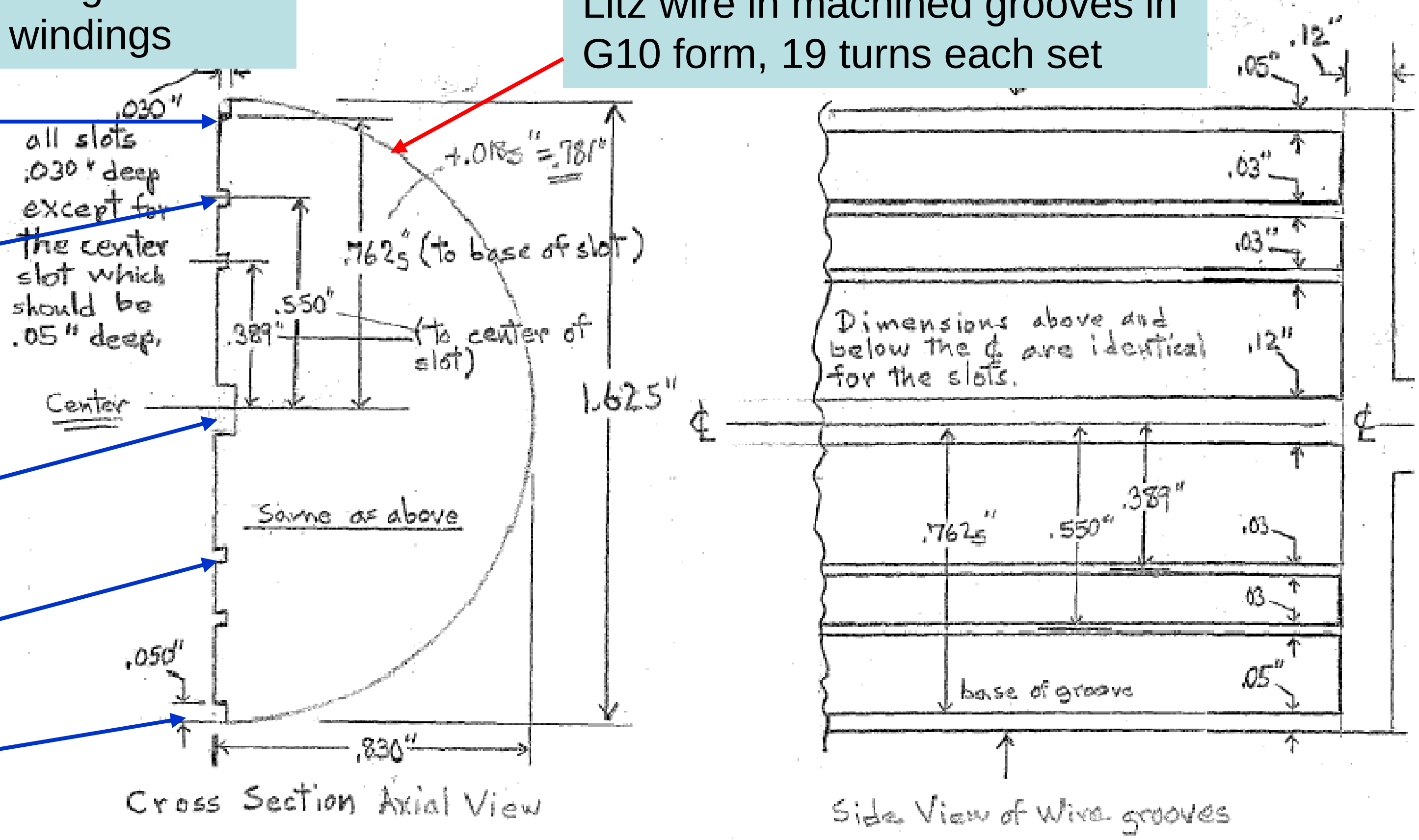
#1 quad coil

Upper quad bucking coil

Center groove where quad coils return

Lower leg of dipole coil

#2 quad coil

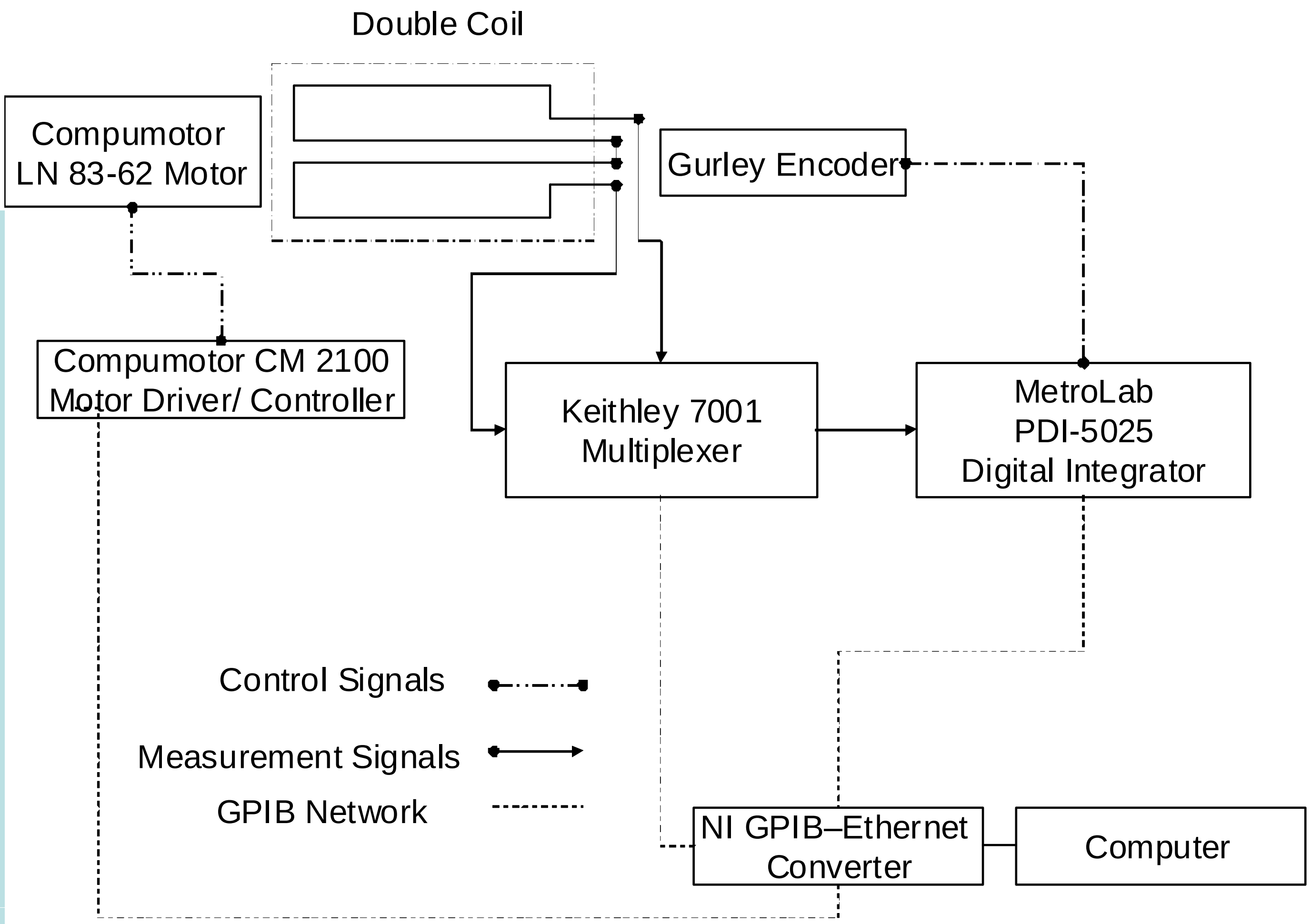


Length of each coil = 1061.7mm

Various combinations of these coils measure strength, harmonics & center

- Quadrupole integrated gradient measured from TWO quad coils in series
  – Reduces effect of coil bowing and of coil offset
- All higher harmonics measured with one quad coil and the two quad bucking coils
  – So quad signal is much reduced and can use more sensitive range on voltage integrator
- If center of rotating coil is not at true magnetic center then measure an apparent dipole; this dipole signal can be bucked out by the dipole coil

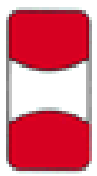
Rotating coil drive mechanism and signal processing electronics



Coil rotates multiple times for one measurement e.g. for a center mst: 13 times at 1Hz in one direction, then 13 in other direction. Use voltages only from middle 8 rotations. Repeat 4 times and average.

Through trial and error find a way to rotate rod without bowing, wobbling or vibrating

Over 3 years tried a variety of bearings to support the shafts at the ends of the G10 rod. Any that needed pressure had bad effects on the rod, so ended up with a “Olive Hole Ring”; shaft sits through center. It cannot move in X or Y and rotates without any wobble.



The shape of the inner contour of an “Olive Hole Ring” jewel bearing which is being used successfully in the best set-up to date.
It is made of very hard, artificial sapphire and costs about $11 !

Finding the **best supports** for the ends of the rotating coil and the magnet itself– again by trial and error

Ended up with mixture of granite blocks and aluminium pieces– could not reproduce this in our superconducting quad set-up in the time available.

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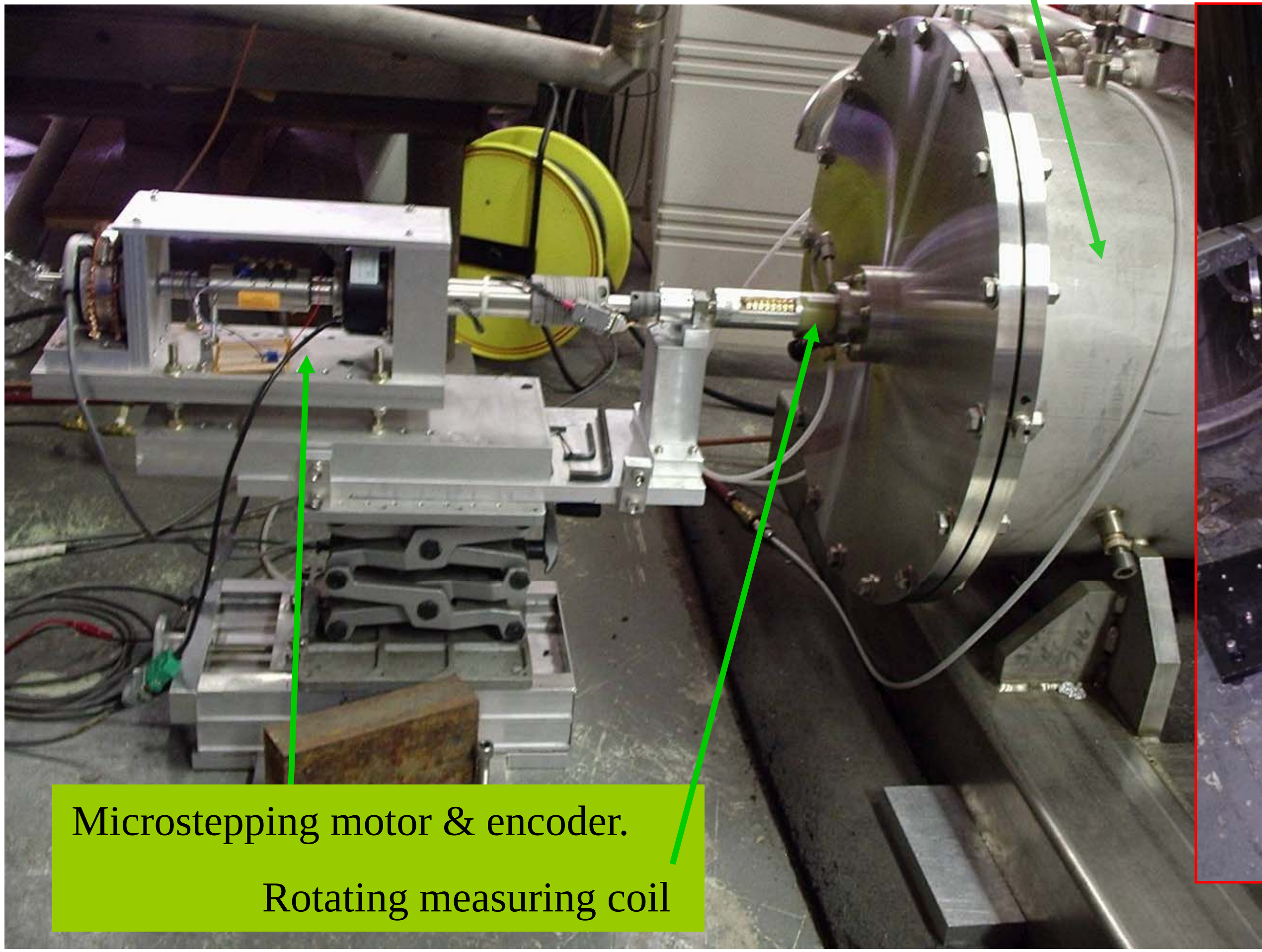
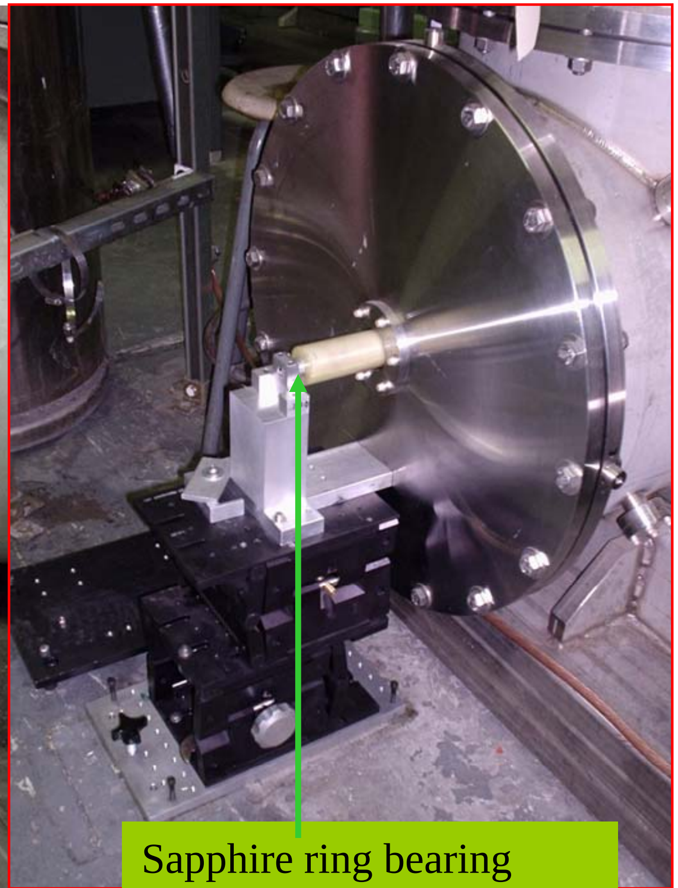
Photos of both ends of the rotating coil which passes through the warm bore of the superconducting quad, QSC990L626.





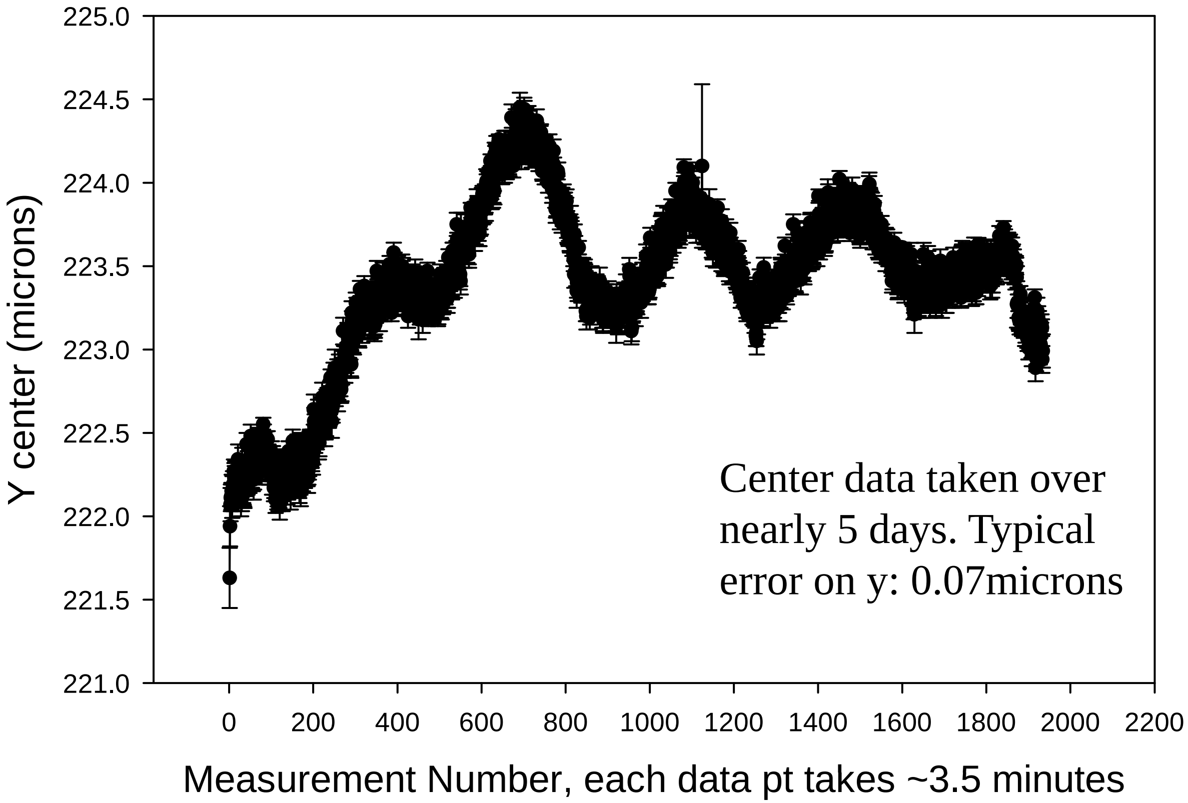
TESTING THE NEW COIL ON AN OLD SPEAR TRANSPORT QUAD with 82.55mm diameter bore, QDMP#1, measured in best environmental conditions in temp controlled room

EXAMPLE showing effect of temperatures of measuring apparatus on Y center (position relative to center of rotating coil)

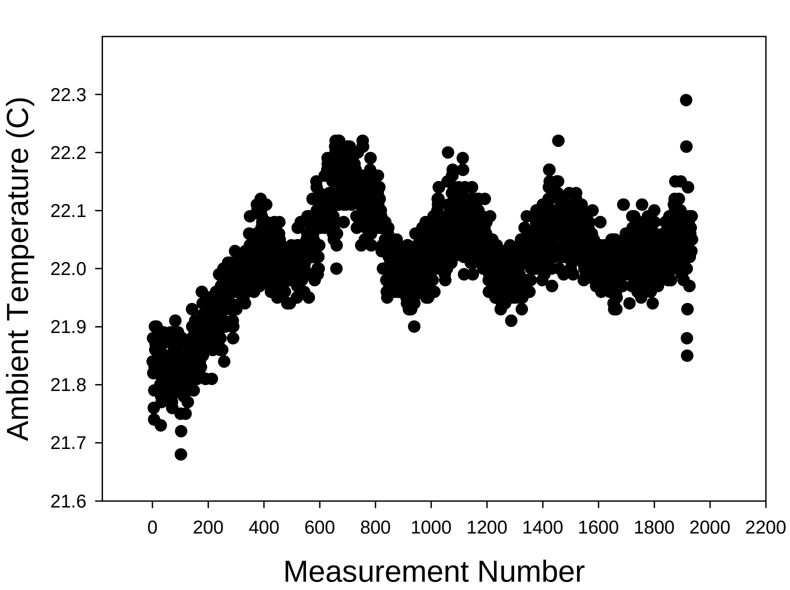
QDMP has solid wire coils with water cooling pipes on their outside-takes many hours to warm up to stable temp.

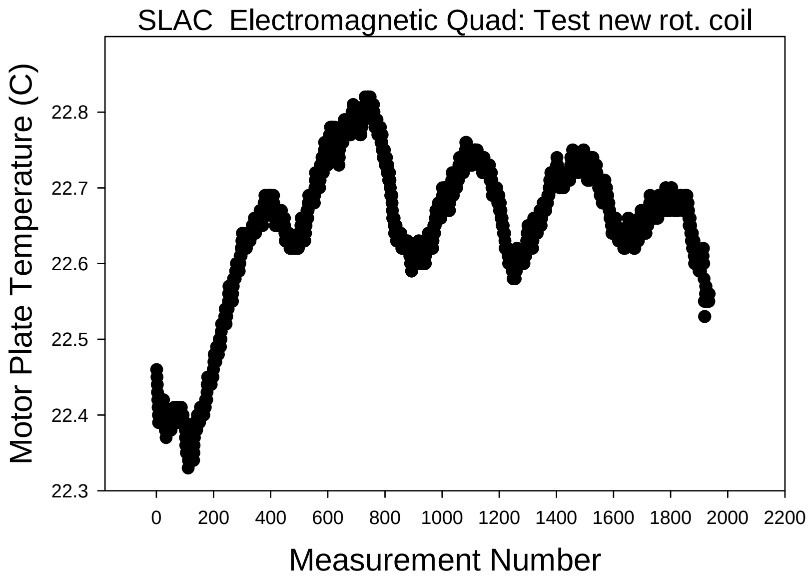
Temperatures measured on same schedule at 7 places around apparatus & Relative Humidity%

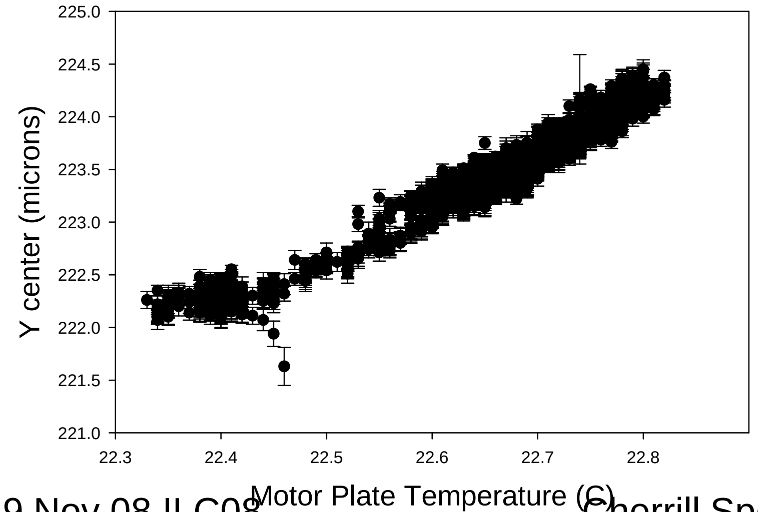
SLAC Electromagnetic Quad: Test new rot. coil

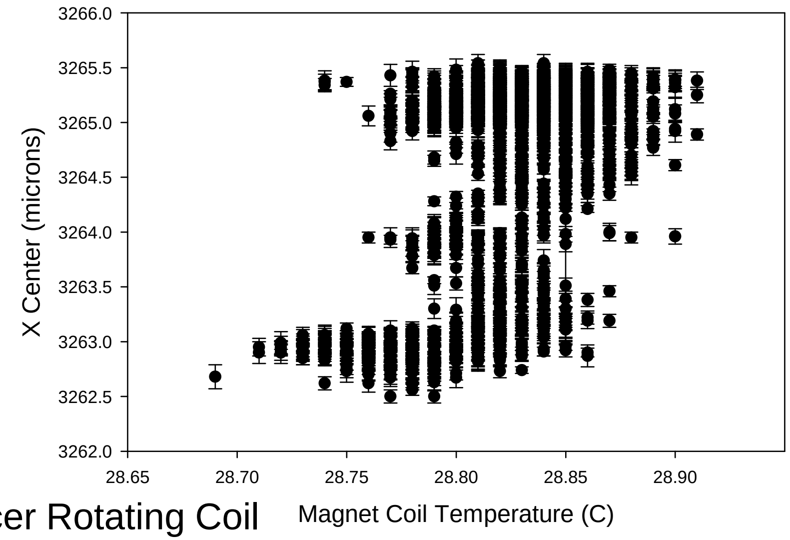


Effects of apparatus temperatures on measurements of a room-temp magnet during a ~ 5 day run in a small room with +/- 0.15C ambient temperature variation.

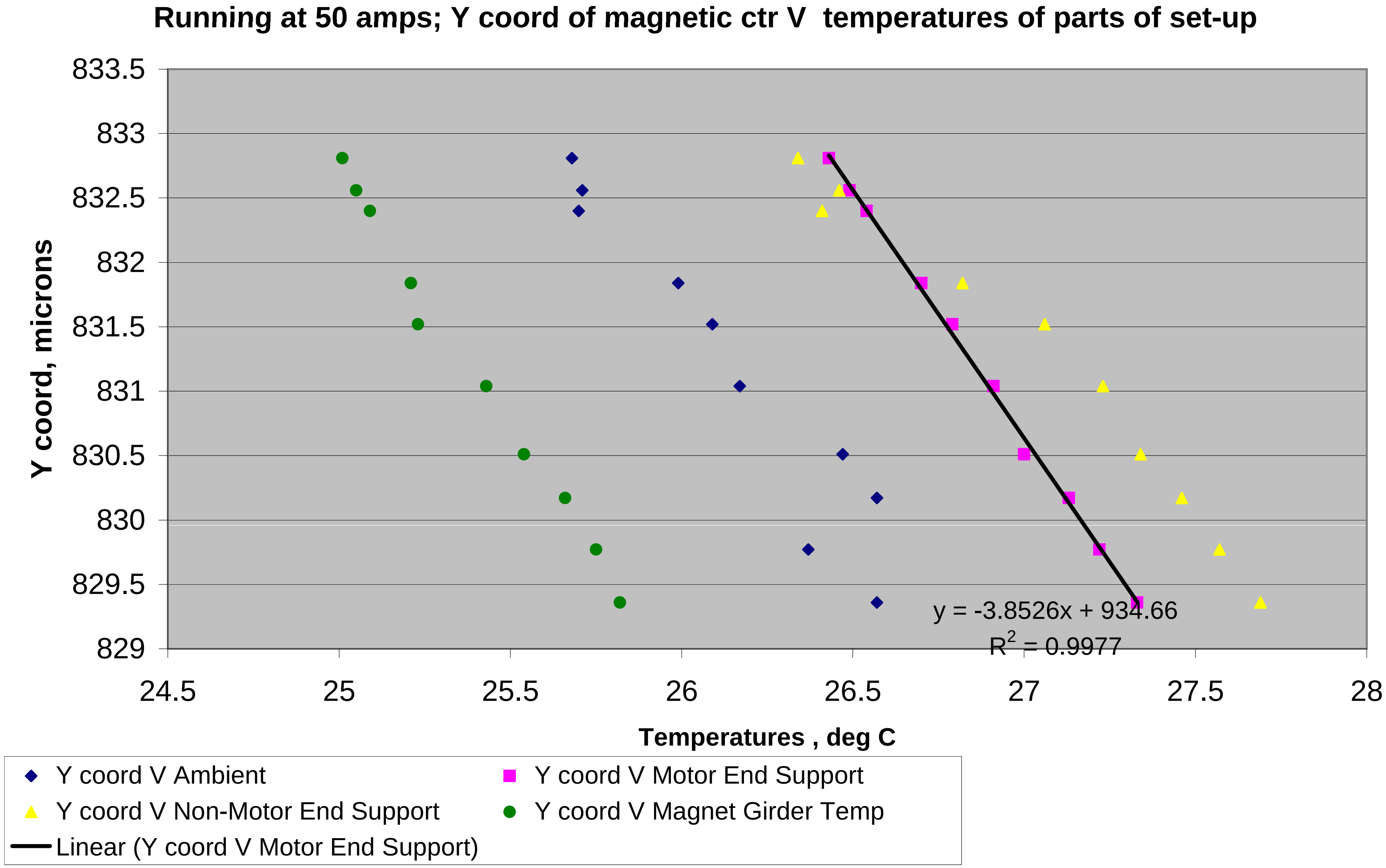








To establish thermal behavior of supercon quad's measuring set-up: measured magnetic center 10 times at 50 amps, closed doors to make lab's temperature increase even more than usual



Lab's room temp was not stabilized, no air-conditioning. Ambient temp varied during day.

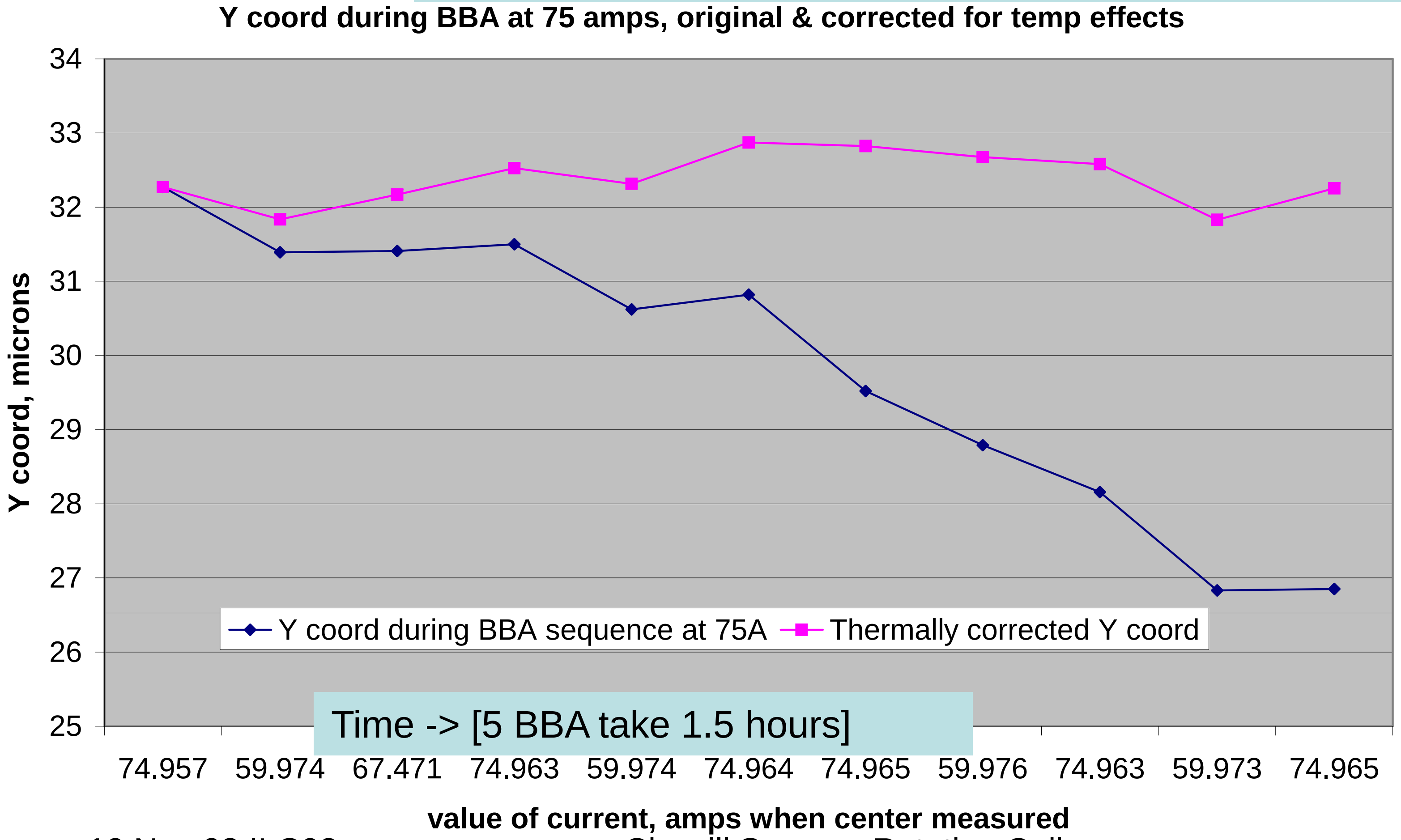
Supports under rotating coil changed height with temperature

We observed: thermal “coefficients” are not consistent, they vary during the day and from day to day. Linearity between Y coord of magnetic center & support temps is clear.

- No one clear reason why the correlation between Y coord and apparatus temperatures has values that vary by up to 100% from one day to another
- We have a complex mechanical set-up with various materials and volumes of materials (more so than the SPEAR quad test set-up)
- Sometimes can observe that the state of the liquid helium in the cryostat affects the center measurements. E g . Overfull, higher flow.

Five BBA current sequences, mostly 75-60-75 amps etc. Measure X&Y coords of magnetic center at each current, and temperatures of 4 parts of rotating coil apparatus.

Corrected Y= Y-(-4.465 x (Temp-Temp at start))



Corrected Y varies by ~ 1 μm. Well below requirement of +/-5 μm

Accuracy and Precision of Magnetic Measurements with this new rotating coil set-up

- The rotating coil is calibrated with a stretch wire set-up which gives an absolute integrated gradient and is accurate to ~0.03%
  - From this comparison the coil is given a constant which is used to relate voltage to integrated strength.
  - Based on experience with re-measuring a reference magnet over many months can say the working accuracy is better than 0.1%
- Coil is rotated many times to make one measurement, use rms variation in about 20 rotations to measure precision : 0.0004% (when power supply is giving very stable current)