NLC News -

November 2000
Volume 1, Number 5

Program Director's Corner:

David L. Burke

Our Program Director is attending the International Study Groups sixth meeting at KEK. He notes that there will be interesting information to report on the NLC budget, so next month look for his comments on both the budget and the ISG-6. (Ed. note)

The Vision: Collaboration and MAC Meeting: Part II

Peter Tenenbaum

This concludes PT's overview of the Collaboration and Mac Meetings:

5) Conventional Facilities. Vic Kuchler (FNAL) and Jon Ives (SLAC) presented results from three "straw man" site studies: a shallow-tunnel site in California's Central Valley, a shallow-tunnel site in Illinois, and a deep-tunnel site which passes through the Fermilab campus. The three sites are remarkably comparable in estimated development costs, and all three estimates have been crosschecked to ensure a fair basis for comparison. Power consumption was discussed at length: recent studies of tunnel temperature regulation indicated that the capital costs of the collider could be reduced by replacing the distributed cooling towers with a centralized chiller, but operating costs would grow due to chiller and ancillary facility power consumption. The conventional facilities crew is working with Accelerator Physics to determine a cooling solution which is an optimal balance of capital costs, operating costs, and tunnel temperature stability (in time and also along the tunnel).

6) Permanent Magnets. Jim Volk, Vladimir Kashikhin and Vladimir Tsvekkov (FNAL) and Cherrill Spencer (SLAC) are designing hybrid permanent magnets for the NLC injector and main linac. Two complete prototypes have been built and tested at FNAL with one tested at both SLAC and Fermilab; the test results agree between the two labs. The results also indicate that the test stands are close to achieving the required micron resolution of quad center measurements. The magnets are also close to achieving this stability. The prototypes demonstrate the stability required for magnets (about 25% of total) in the injector complex*. (Ed. Note: See the following article by Cherrill Spencer.*)

The next meeting of the NLC collaboration will be in February 2001 at Fermilab, while the next meeting of the Machine Advisory Committee is tentatively scheduled for May 2001 in Berkeley.

The NLC Electromagnetic Quadrupole Development Program

Cherrill M. Spencer

The September 2000 "NLC News" contained an article on the "Development at Fermilab of Permanent Magnet Quads for NLC," at the end of which was promised an article on the electromagnet development program. This is it! This program started just over three years ago when a multidiscipline engineering team was assembled at SLAC to develop a more reliable design than historically had been achieved at SLAC for the 1500 DC quadrupole magnets and associated power systems in NLC main linac.

The electromagnetic main linac quads were subjected to a reliability-based design process centered on the Failure Mode and Effects Analysis (FMEA) method that the team followed during a year of weekly meetings. This first FMEA pass-through overcame a number of long-standing design prejudices and produced 10 major magnet design changes from a typical SLAC magnet. Amongst these changes are the use of *round* hollow copper conductor instead of square, the separation of current and water connections and the use of a commercial current disconnect for the connection between the long-haul cables and the magnet power terminals, instead of torque carrying connections. The accelerator physics requirement of an exceedingly stable magnetic center (see below), led us to choose a solid, EDM profiled core over thin laminations. A detailed description of this novel design process and the resulting NLC main linac quad can be found in [1].

The NLC beams must be centered precisely as they pass through the linac quads (and the accelerating structures) to avoid emittance growth. Computer simulations show that if the beam is as little as 3 µ away from the magnetic center (where the field is zero) emittance growth will be 100%. Because all other alignment techniques do not have 1-2 µ accuracy we will use a *beam-based* alignment (BBA) process occasionally to measure the position of the quads relative to their captured beam position monitors (BPM). Between the once-a-month or so BBAs some steering algorithms, using BPM data, will be used continuously to tell the magnet movers where to move the quads so the beam remains centered. The BBA process sets the following requirement: while the magnetic strength of a linac quad is changed by 20% from its operating strength, its magnetic center must not move by more than 1 µ. In order for the BBA to occur in a timely fashion each of its 5 strength-changing steps must take less than 5 seconds. Furthermore, for the steering process to work, the quad's center must not change by more than 2 microns relative to its BPM's position during its regular operation.

One could imagine an aberrant electromagnet (em) with steel quadrants that differ in permeability, or coils with very small shorts that come and go with current variations or coils that heat up and shift differently, and one could calculate disturbingly large magnetic center shifts. But the only way to find out if a quad can satisfy the 1-µ requirement is to build and measure it and that is what we did over the past year. Carl Rago was in charge of the drawings and fabrication, which were all done at SLAC.

The prototype quad has a 1.27-cm bore diameter, 21.59-cm long low carbon steel core and 21-turn potted coils wound from 0.25" OD round hollow copper conductor with a 0.125" ID. It runs up to 152 A where its pole tip field is 1.0 T and integrated strength is 3.5 T. It weighs 127 kG and each coil has its own low conductivity water (LCW) circuit so the temperature rise is kept deliberately low: 3.2˚ C at 160 A, to minimize the thermal excursions introduced by changing the current.

The SLAC Magnetic Measurements Group, led by Zack Wolf, typically use rotating coils to measure the harmonics and magnetic center of quadrupoles, but they have never before been asked to measure the magnetic center to fractions of a micron and they made a new rotating coil set-up with several significant improvements over their typical apparatus. The accompanying photo shows the prototype em being measured in the new set-up under Zack's watchful eye. It is most important that the axis of the rotating coil not move relative to the magnet, that the apparatus not be disturbed by local ground movements/vibrations and that it be kept at a stable ambient temperature. Thus, all the apparatus sits on a large granite table and it is completely covered by an insulated box with a window and small holes for cables to pass through. This "thermal hut" has been removed for the photo. Furthermore, each end of the rotating coil sits on granite blocks and the magnet sits as close to the table as possible on a "home-made" moveable support so we can deliberately move the magnet a few microns to test the set-up's sensitivity.

The rotating coil has two sets of windings of 50 turns each. They are wired in series-opposition such that the main quadrupole signal is bucked out before amplification and so we just measure the small odd harmonics signals. This set-up, together with a high precision hollow shaft encoder, a

Zack Wolf, head of SLAC's Magnetic Measurement Group, with the NLC Prototype electromagnetic linac quadrupole in the SLAC rotating coil measurement set-up.

microstepping motor (visible on the left in the photo) and a high quality voltage integrator, enabled us to get repeatable and believable measurements of X and Y magnetic centers under stable ambient thermal conditions. The air temperature inside the hut varied by less than 0.5˚ C. We have limited the number of rotations the coil makes to 16 for one measurement, so we can get a measurement of the centers within 3 minutes of a current being reached, but still maintain an excellent statistical error. So we do NOT wait for the magnet to reach a new thermal equilibrium when its current has been changed—we are trying to mimic how the magnet would be used during BBA.

We measure the temperatures of the core close to the pole tip, at the end of the core (yoke), and the coil on its outside. We can see the core and coil temperatures change, by 0.5˚ to 1.3˚ C, as we change current. I believe part of the coil temperature changes come from the incoming LCW changing temperature – currently we have no control over the incoming LCW temperature.

We are measuring X and Y magnetic centers with "statistical" errors of 0.01 to 0.2 µ, that is the rms deviation of the signals from 16 rotations, the errors are below 0.10 µ most of the time. The centers vary by less than 0.6 µ for periods of 1-2 hours if one does repeated measurements with no current or thermal changes. So the set-up is sensitive to changes of 0.5 µ or more. We will be making much longer runs in future.

The BBA requirement is: the center mustn't change by more than 1 µ when we change the magnetic strength by 20%. I can report that the em prototype satisfies this criterion when we change its current in one step from 150 A (the maximum) to 120 A, *as long as we approach the 120 A from below*. We cycle the magnet thus: 150-5-120 or thus: 150-100-120-150-100-120 etc and the centers at 150 A and the next 120 A differ by amounts such as 0.4 µ or 0.88 µ.

We can even change from 150 A to 75 A and satisfy the less than one micron as long as we go to a current below 75 before we go to 75 A. When we return to 150 A again then the centers are within 0.6 µ or better of where they were when the magnet was last at 150 A. The only drifting of centers we have observed during multiple current cycles has been the Y center, correlated with an upward trend in the core temperature.

If we change the current from 150 to 120 A directly then the X center varies by between 1 and 2 µ (but not more) and the Y always by less than 1 µ. We have not yet changed the current in 5 steps of 4 A each. We chose to use a +/- 1.1 A/s equivalent linear ramp rate with a cosine-shaped curve, to minimize any eddy-current-induced center shifts. With this slow ramp rate we just miss the requirement of less than 5 seconds to change the strength by 4%. We intend to try faster ramp rates until the center shifts too much, if at all.

These results are a very encouraging beginning and we will be doing many more experiments in the next few months as mentioned above and will test various possible influences on the magnetic center behavior. The prototype permanent magnet quads will be tested in the same apparatus.

1. Paul Bellomo, Carl E. Rago, Cherrill M. Spencer, Zane J. Wilson, "A Novel Approach to Increasing the Reliability of Accelerator Magnets," *IEEE Trans. Applied Superconductivity*, **10** (1): 284-287 Mar. 2000.

New Electronics Department
Ray Larsen

Two departments, Power Conversion and Controls, primarily have supported the Pulsed Power, Controls and Instrumentation development work of the NLC. In early October these departments, reporting to Assistant Director of the Technical Division Ray Larsen, have been combined into a single entity named the Electronics and Software Engineering Department (ESD). Rusty Humphrey with Tony Donaldson as Deputy heads the new department. Among the reasons for the reorganization was to build larger subgroups with more mobility to respond to the full range of development, systems engineering and sustaining engineering needs demanded by the ongoing programs at SLAC as well as high-profile R&D programs like NLC. In addition, ESD will develop a set of core long-range R&D activities designed to equip the engineering staff to respond to future demands with the most up-to-date technology available. NLC will continue to be a major driver of the core programs.

Modulator Developments: NLCTA and 4-Dog, *Ray Larsen*

Modulator developments continue to be a major activity of the Power Systems Development group. In early September the development work of assembling the solid state induction modulator was slowed as key engineering personnel were diverted to a more urgent situation, namely to upgrade the modulators and related power controls equipment in the NLCTA. This program assumed top priority as problems were discovered with the test accelerator structures, since the NLCTA is the only test facility with the power capacity and number of stations necessary to advance the work. Unfortunately NLCTA was running at very low efficiency so a program was undertaken to bring machine availability to at least 75% when running on a 24-hour basis. A large team was assembled to attack problem areas including power systems, controls, interlocks, rf cable plants and machine and structure diagnostics. The cooperating departments were Power Conversion, Controls and Klystron. The work is ongoing, with maintenance support now coming into place on a three-shift basis. So far the controls for the modulator power supplies have been updated with new designs and software, many problems in the high voltage sections of the modulator tank, thryraton and power feeds have been diagnosed and eliminated, and operational time has improved to well over the 75% target. Many small factors are still contributing to high voltage trips, and work continues to eliminate these as well as to automate operation more fully in recovering from trips. The Controls group has designed an upgrade path for both controls and data acquisition which comprises expansion of diagnostic channels and integration of the current fragmented system into the main control system under an EPCIS control program.

Wes Asher points to the new PLC SmartTouch screens recently installed in NLCTA modulators

The so-called 4-Dog IGBT Solid State test modulator is beginning assembly in the Power Systems group laboratory under R. Cassel. The first cores have been stacked and leak tested with insulating oil in the stack. Due to curvature of one of the bottom plates, leaks were discovered which halted the stacking until a solution was found. Most of the associated circuit boards are now in hand and final assembly is proceeding. The original goal was to begin live testing in January. The high voltage single-turn transformer for the first stage of testing is being assembled at LLNL.

Recent Linear Collider Publications
If you would like an NLC-related paper listed, please send information to amlarsen@slac.stanford.edu

I. Linear Collider Collaboration Notes
LCC-00048, "Damping Ring Design for NLC at 180 Hz Repetition Rate," Andrzej Wolski 11/00.

Calendar of Upcoming Events
2001 Particle Accelerator Conference, Chicago, IL, June 17-22, 2001.

2001 Nuclear Science Symposium, San Diego, CA, Nov. 4 – 6, 2001. Abstract deadline, April 20, 2001.

ICALEPCS 2001, San Jose, CA, Nov. 27 – 30, 2001, Abstract deadline April 20, 2001 http://icalepcs2001.slac.stanford.edu.