Lessons Learned from FDC Visit to FNAL

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On January 25, 2007 Daniel Carman, Simon Taylor, Brian Kross, and Tim Whitlatch visited the wire chamber lab at Fermilab (FNAL) to discuss details of design of the Forward Drift Chamber (FDC) system with Karen Kephart. Karen is the group leader of the FNAL wire chamber lab. The meeting lasted from roughly 10:00 a.m. to 4:00 p.m. and included a tour of the wire winding lab. We are also in negotiations with FNAL to do the wire winding for the FDC planes and for the full-scale prototype. This document represents a report reviewing the discussions. The agenda for the meeting is included in the appendix to this document, however, not all agenda items were formally discussed.

The main areas of discussion during our visit included:

- Wire Frame Design
- Sense and Field Wires
- Tensioning Requirements
- STB and HVTB Design
- Package Construction
- Frame Material Choices
- Survey and Alignment Options
- Chamber Grounding Scheme

The discussions related to each of the above areas is included below, especially with regard to validating our nominal design or changes to our nominal design choices. The first order of business upon our arrival was to provide Karen with a thorough general overview of the nominal FDC design so that she could understand the system and the current plans for the FDC package design, the design of the cathode boards and the wire frames, the material choices and specifications for the chamber frames and circuit boards, the electrode structure, and the overall construction plans.

1 Wire Frame Design

1). The circular design of the FDC system was seen as an advantage from the standpoint of minimizing deflections of the wire frame. Given the planned wire tensions on the wire frame, Karen believed that there should not be any need to pre-tension the frames. If our finite element analysis of the deflections caused by the wire loads indicate deflections outside of acceptance tolerances (on the order of a few millimeters), then the pre-tensioning scheme would be relatively straightforward. Karen recommended that we wind a test plane to learn about the distortions via direct measurements. It is also the case that any distortions in the wire frame that are brought about by the wire tension load could be eliminated once the frames are built into the FDC package.

2). The wire winding process begins by first winding the sense and field wires on the winding table. This is actually performed in two steps. First one wire type is wound, and then the other wire type is wound. We need to consider if we want the wires to be wound onto the table at the same time or separately. The main issue involved is illustrated in Fig. 1. If the wires are wound onto the table at the same time, we are presented with a slight vertical positioning misalignment as shown in Fig. 1(a). If the wires are wound separately, then the sense wires can be shimmed such that they are coplanar with the the field wires as shown in Fig. 1(b). The standard technique is to wind the wires onto the table at the same time. This ensures better sense-field wire placement uniformity. However, positioning the wires so that they are coplanar gives rise to a more uniform electric field. In either case the soldering is done by hand with a soldering iron and the flux flows around the wires to fix them to the pads. Karen indicated that the separate winding method could give rise to half gap non-uniformities of 1-2%. She also indicated that the impacts of the single winding could be studied via tests on planes wound in each manner. Note that the solder does not hold the wires in place. This is the purpose of the glue strips. Calculations should be done to understand the impact on the cathode performance (see the Sauli write-up for background information).

Figure 1: Two scenarios for positioning the sense and field wires relative to the solder pads. (a). The wires are in direct contact with the solder pads. (b). The sense and field wires are coplanar.

3). It would be very preferable if the solder pads that we included on the STBs and HVTBs were of different lengths to allow a simple visual check that the wires are overlaid on the appropriate pads. This is probably a natural thing to do given the different tensions associated with the sense and field wires. Different tensions mean that the shear forces on the sense and field wire pads will be different, and a longer pad length for the field wires is appropriate.

4). Wire placement accuracy on the solder pads was estimated by Karen at ∼2 mil. After the wires are soldered into place, they will be measured to ensure that the spacing is within tolerance. The measurements will also be done at both ends of the wires to ensure that any tilts of the wires are measured. Any wires outside of tolerance will be restrung. The measurement accuracy is at the 1 mil level.

5). Karen recommended that we use wire alignment targets on the STB and HVTB boards as shown in Fig. 2. These targets need to be specified with a tight precision. They should be located on all three of our STB and HVTB boards for easy reference. They allow for a rapid visual check on wire alignment and rotations of the wire frame relative to the wires.

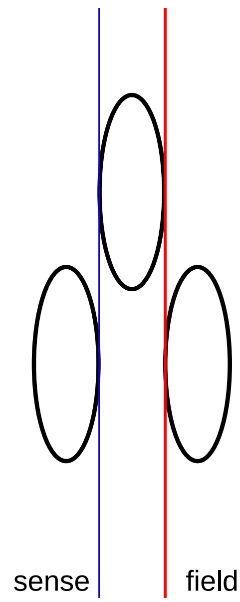

Figure 2: Alignment target scheme recommended for all three STB and HVTB boards.

6). Karen recommended that we design a plate to keep the wire frame flat during the winding process. The chamber would then be strung with our nominal choices for tension. After the stringing is complete, the backing would be removed and we would allow the plane to distort. This would serve to relax the tensions. The frame would be stored in this configuration until chamber package assembly. The tooling on the chambers should then force the frame back into the shape it had during stringing, thus restoring the tensions.

7). After the wire frame is positioned at the correct height relative to the wires, a glue strip is placed down over the wires by hand. The glue strips should be at least 3 mm wide with at least 1 mm of space on either side to allow epoxy seepage. Karen stated that having a circular glue strip would not be a problem for her.

2 Sense and Field Wires

1). Our nominal wire choice has been 20 μm diameter gold-plated tungsten for the sense wires and 80 μm diameter gold-plated aluminum for the field wires. Karen thought that we should use gold-plated copper-beryllium for the field wires due to fact that it is readily available and she has used it as her wire of choice for years. She stated that Cu-Be wire is much easier to handle than aluminum and is easier to solder to. We decided to consider Cu-Be as our nominal choice for the field wires.

2). Karen also discussed with us the wire diameter for the sense wires. She stated that 25 μm diameter gold-plated tungsten is more readily available compared to 20 μm diameter. She also stated that it is much stronger than the 20 μm diameter wire, and would strongly reduce the possibility of wire breakage. However she was not that worried about breaking the smaller diameter wires. The issue is that in order to achieve the same chamber gain, we would have to operate at higher voltages to achieve the same electric field around the wire. This in turn could lead to more problems with leakage currents and sparking. This is something that we will have to decide for ourselves after we do some more thinking about it and possibly prototype a chamber with the thicker wire. Note also that with a thicker wire, increasing the high voltage to achieve the same gas gain would lead to a larger effective drift velocity. This would lead to an increase in Lorentz angle effects.

3). Karen recommends California Fine Wire Company for the tungsten and aluminum wires and Little Falls Alloys for the Cu-Be wire.

4). The wire deadening plan is to electroplate a few mils of copper onto the wires around the central beam hole. This increase in diameter very effectively kills the gain along this portion of the wire, but does not affect signal quality or chamber operation on the uncoated portion of the wire. Karen recommended that we only electroplate the sense wires and leave the field wires alone. This is our nominal decision. However, if we have concerns, this can be easily prototyped. Karen also stated that she would recommend that we perform this procedure ourselves at JLab. She will provide all necessary information.

5). The wire should be procured as continuous spools, with a minimum length of 2 wire planes ($\sim$1.2 m) plus a waste factor of 10%.

3 Tensioning Requirements

1). In selecting the wire tensions, we should set the tension at no more than half the yield strength to reduce the probability of breaking wires. This represents the maximum tension. The minimum tension should be set safely above the point of electrostatic instability. Our nominal tension choices of 20 g for the sense wires and 140 g for the field wires seems appropriate, but needs to be checked. The tensions in the sense and field wires should be set to match the gravitational sag (sagitta) on the wires.

2). The tensioning accuracy on the wires when wound on the wire-winding machine is about 5%. This is what we should consider as our tolerance.

4 STB and HVTB Design

1). We discussed the notion of prestuffing the STB and HVTB boards prior to wire winding. This is our natural choice to reduce the probably of wire breakage during later handling. Karen did not see a problem with this choice provided that their was sufficient clearance for the wires between the components. Given our current design, the surface-mount resistors can stay on the top of the boards, but the HV-isolating capacitors on the STBs will have to be buried on the back side of the board. They are just too big. Karen did not see any problems with doing this, but suggested that we bury them in such a manner as to increase the physical path length to the cathode planes to minimize "charge creep" along the surface. This will give us the best hope of designing quiet chambers, with minimal leakage current. Fig. 3 shows two concepts for placing the capacitors on the back of the STB board, both of which involve leaving a ledge of the STB overhanging the edge of the G10 annulus that supports the PC board. In Fig. 3(a) the design minimizes the length of the overhang to give the most support to the STB board and the wires. The drawback here is that the trace routing is more complicated as the trace from the solder pad must double-back through the STB to connect to the capacitor. In Fig. 3(b), this problem is eliminated, but the overhang length of the STB is much longer. The design needs to be finalized via finite element analysis to understand the issues before we can finalize the design. Note that we are not far enough along in the design of the HVTB to understand the component placement issues.

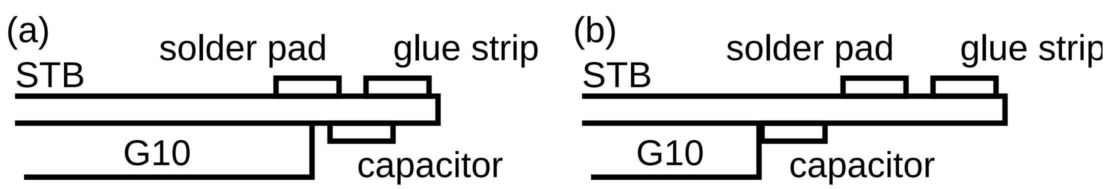

Figure 3: Two scenarios for burying the HV-isolating capacitors on the STB on the back side of the circuit board. (a). The overhang ledge is minimized but the connection to the capacitor is more complicated. (b). The connection to the capacitor is straightforward, but the unsupported ledge of the STB is longer.

2). We might consider a flash of gold plating on all areas of the boards where components or wires will be soldered. This allows for easier soldering and these areas are then more immune to oxidation.

3). We discussed whether we should include a solder mask on our STB and HVTB boards. A solder mask is the final coating applied to the surface of a PC board. It provides environmental protection, encapsulates surface circuitry, and acts as an electrical isolation barrier for electronic assembly. Karen stated that a solder mask is entirely optional and that she has no preference if they are included or not.

5 Package Construction

1). We discussed the modular design of our FDC packages. Karen thought that it might be a good idea if we could design cathode-anode-cathode assemblies that could be kept together during disassembly of the packages. With our current cathode sandwich design, this is not a workable option. However if we move to develop cathode planes without a backing, we should consider developing sub-assemblies within the FDC that can stay connected during disassembly.

2). Presently we are planning to use standard round o-rings for all of our gas seals. Karen recommended that we look into alternative cross section o-rings that have a star shape for better sealing.

6 Frame Material Choices

Karen understood our choice of frame material for the wire planes and cathode planes of G10. This is a standard choice. However she also recommended that we move to Stesalite if we can afford it as it has much better machining characteristics. G10 and Stesalite are both essentially fiberglass composites, but the glass strands in G10 are laid out in a two-dimension pattern and those in Stesalite are laid out in three dimensions. When G10 is skim cut to get the desired flatness or thickness, the strands then relax out into the third dimension. This does not happen with Stesalite. It is known that Stesalite is typically much more expensive than G10. Karen also recommended that we seal any exposed G10 surfaces with epoxy to ensure gas tightness and surface properties.

7 Survey and Alignment Options

Karen stated that the best advice that we could get would be from the folks that will actually do the surveying, namely the JLab Survey Group. We will set up a meeting with them upon our return to understand what would make their survey of the FDC the easiest.

8 Chamber Grounding Scheme

Karen recommended as a good practice to use as much ground space as possible on the STB and HVTB boards. Everything that can be defined as ground, should be. This allows for the quietest possible chamber design.

9 FNAL Work and Schedule for the FDC System

1). Karen provided us with a complete tour of the wire-winding facility at FNAL. They have a state-of-the-art facility with all of the required infrastructure to wind and store all of the FDC planes. We are asking that FNAL wind the planes, measure the wire positions, and measure the wire tensions. All wires whose position or tension are out of our tolerances will be restrung.

2). Karen will work with the FNAL management to put together a quote for the FDC wire-winding work. She stated that we would have to provide all backing plates, tooling, storage units, and construction materials. The nominal plan is that we will drive out to FNAL and pick up the wire frames after they are all wound. Karen also suggested that we provide her the earliest opportunity to wind some test frames to work out the details and test the specifications.

3). The wire chamber lab at FNAL will be in operation until about 2010. After that it will close down. We need to make sure that we keep this in mind, as well as the uncertainty in the closing date when we plan our schedule. The sooner an agreement is reached and a time frame is defined, the better. We agreed to work from our end to get an MOU in place for this work.

4). Karen recommended that when we transport the wire planes, we arrange to ship them in a vertical orientation. This positioning will decrease the chances of wire breakage when going over rough roads.

5). After the meeting was completed, Karen prepared an initial budget estimate for the work and a time table for completion. She assumed in her estimates that a technician will be assigned to the FDC project full time, a senior technician will be assigned half time, and a senior operations specialist will be assigned at 5% FTE. She assumed that two wire planes will be strung and tested per week. Given the 24 planes of the FDC system, this gives a time frame from start to finish for the production wire winding of about 3 months. The budget estimate for FNAL labor is estimated at about $65k. In addition to these costs, we need to include in the budget materials (epoxy, wire, tools) and items such as the frame backing plates and storage/transport containers. We envision the storage containers will be gas tight and filled with nitrogen to keep a clean and inert environment for the wires.

A Agenda for FDC Meeting at FNAL Thurs. Jan. 25, 2007

1). **FDC System Overview**:

Discussion: We should review the overall concept of the FDC system including its design requirements, general layout, and constraints.

2). **FDC Chamber Design**:

Discussion: We should review in detail the nominal design of the FDC chambers. This includes:

Issues:

- Electrode structure;
- Anode board layout;
- Cathode board layout;
- Arrangement of wire layers in each package U, V, and W (with no stagger);
- Angle of orientation of each wire layer;
- Orientation of cathode strips with respect to the wires;
- Edge effects;
- Readout systems;
- Package design;
- Material choices;
- Wire attachment procedure (glue strip + soldering);
- Solder pad size.

3). **Wire Diameter Choice**:

Discussion: We need input to make a final choice on the sense wire diameter. There are two options currently being considered: 20 μm and 30 μm gold-plated tungsten.

- Reduced probability for wire breakage with thicker wires;
- Larger drift velocity with thicker wires at the same gain;

Issues:
- Higher operating voltage with thicker wires to achieve same gain;
- Potential stability and current issues at higher gain;
- Impact on chamber life time at higher gain.

4). **Sense and Field Wire Material**:

Discussion: The nominal choice for wire material is gold-plated tungsten for the sense wires and gold-plated aluminum for the field wires. This was the option employed for the Hall B chambers. Given other material choices like stainless steel and copper-beryllium, what are the pros and cons of each choice? Which is/are the best option(s) for vendors? What criteria should we apply for quality control?

5). **Tensioning Requirements**:

Discussion: What should we consider in determining the appropriate tensions to employ for the sense and field wires.

Issues:
- Need to balance minimizing gravitational sag against the increased forces and possible distortions on the support frame.
- The lower the wire tension the smaller possibility there is for wire breakage. However with smaller tensions the possibilities increase for high-voltage instability and non-uniform electric fields.

6). **STB Layout**:

Discussion: Review the general layout of the STB design, including readout circuit design and component choices (e.g. values, tolerances, and ratings), spacing, adequacy of ground plane definitions, minimization of cross-talk, and potential for high-voltage breakdowns. What coatings should we apply to the STBs to reduce corrosion and humidity-related problems?

7). **HVTB Layout**:

Discussion: Review the general layout of the HVTB design, including HV circuit design and component choices (e.g. values, tolerances, and ratings), the bus spacing, adequacy of ground plane definitions, and potential for high-voltage breakdowns. What coatings should we apply to the HVTBs to reduce corrosion and humidity-related problems?

8). **Readout Choices**:

Discussion: Review the nominal choices for the preamplifier, preamplifier with on-chamber discriminator, and pulse-shaper circuit.

9). **Serviceability Issues**:

Discussion: Review whether there are any aspects of the design that should be modified or incorporated to improve the serviceability of the chambers, reduce access time, allow for longer life time, easier access, and more steady performance vs. time? In this process we need to identify the possible failure modes and the techniques and/or design approach to mitigate the problems.

10). **Gas Choice**:

Discussion: Presently we are operating with 90/10 Ar-CO_2 in our test chamber. The FDC system will be operated in a 2.2 T solenoid. What gas mixtures would you recommend we consider to enable the easiest time-to-distance calibration, smallest Lorentz angle, and fastest drift velocity?

11). **Frame Material Choices**:

Discussion: Our chamber frames will be constructed from g10 and CH_2. Are there other material choices that we should consider to increase rigidity and to minimize the material thickness for the inactive portion of the chamber? At issue is the impact on the detector sub-systems outside of the FDC system.

12). **Cathode Board Layout**:

Discussion: Review the layout of the current cathode strip plane design, including strip pitch and strip gap. Can you provide information on the optimization of the cathode strips boards? We are starting to consider capacitive coupling of neighboring strips to reduce the channel counts without sacrificing resolution in this measurement?

13). **Survey + Alignment Options**:

Discussion: How should our design be modified to make the survey and alignment of the chambers as easy as possible? We can also talk to the JLab survey group to get their input.

14). **Gas System Design**:

Discussion: Review layout of the design and plans for FDC gas system.

Issues:

- Are the controls that we have planned adequate?
- Are our current plans for gas exhaust monitoring for H_2O contamination adequate?
- Review our current design for distributing gas to the individual chamber packages and layers.
- Is our gas system as designed sufficiently flexible in case more complex gas mixtures are required?
- Is our gas system as designed sufficient to ensure chambers are protected in case of over and underpressure situations?

15). **Budget Review**:

Discussion: Review the FDC system budget. Given the budget categories, is there anything that we have overlooked that may lead to significant cost increases? Is there anything in the design that we have not accounted for?

16). **Chamber Cooling and Monitoring**:

Discussion: Review plans for cooling of the preamplifiers. Will this design be adequate and is there anything else that we need to consider about the external chamber monitoring? We plan to monitor temperature and humidity at several points on each chamber and each layer. Is there anything else that we should plan on monitoring?

17). **Chamber Grounding Scheme**:

Discussion: Is our planned grounding scheme adequate to minimize ground loops and provide appropriate layer-to-layer and channel-to-channel isolation?

18). **Chamber Calibration Issues**:

Discussion: Review the basic design of the preamplifier daughter board design. Have we overlooked any aspect of the design that would enable improved relative and absolute gain calibrations of our preamplifiers?

FNAL Statement of Work for the GlueX FDC System

- What we are asking FNAL to do for the FDC system:
  - Wind the 24 wire planes of the FDC system with our choice of wire and wire spacing.
  - Measure the wire spacing of each plane after winding at both ends of the chamber to ensure the wire positioning is within specifications.
  - Measure wire tensions of sense and field wires after winding to ensure that they are within specifications.
  - Work with us to address the question of pre-tensioning the wire frames. If this is viewed as important to minimize frame distortion or unusual large forces after assembly, work with us to develop a technique.
  - Apply conductive coating to wires in central beam hole to a radius of 5 cm. Precision of procedure.
  - Discuss options for storing the wound planes until they are ready for assembly.
  - Work with the GlueX FDC representatives during the wire winding and testing process to ensure specifications are met and questions are addressed.

- Relevant questions:
  - What are the associated charges from FNAL to JLab for this work?
  - Can the wire planes be strung after the boards have been stuffed?
  - Are our specified tolerances on wire positioning and tension reasonable?
  - Is there any need to prototype any of the aspects of the chamber construction at FNAL?
  - Will there need to be any design effort at FNAL?
  - How long will it take to complete the work?
  - What time frame is available for this work?
  - How can we formalize this work agreement and who should we be in contact with?