STAR Note 0040
WBS 4.2

Notes on DELPHI and ALEPH TPC Construction

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Trip Report
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Traveler: Roger Stone

Position: Senior Staff 3, Mechanical Engineering, High Energy Group

Destination: CERN, Geneva, Switzerland, Feb. 13-14,1992.

Meeting: Held discussions at CERN with:
Hans Hilke, Head of DELPHI TPC
Henrik Foeth, DELPHI assembly engineer
Werner Witzeling, ALEPH installation and test
Wolfgang Rictner, ALEPH design engineer
Micheal Bastette, Inventor of "leakless" cooling system
Mike Price, ALEPH field cage designer

Purpose of trip

The Lawrence Berkeley Laboratory has responsibilities for designing, fabricating and assembling a time projection chamber (TPC) for the STAR detector at the Relativistic Heavy Ion Collider (RHIC) located at Brookhaven National Laboratory. The ALEPH detector at CERN includes a TPC as a major subsystem. It was recommended by the STAR technical advisor committee that the proposed TPC use as much of the ALEPH design as possible. By visiting CERN and discussing this TPC with key personnel the effort at LBL will be more effective. This sharing of information should considerably reduce the design and assemble effort.

Trip summary

Discussions were held with the above personnel (except Micheal Bastette) concerning the design, fabrication and assembly of the DELPHI and ALEPH TPCs. In addition, tours of the two detector halls were made. TWQ of the major components of the TPC were covered in more detail than others. These were the outer field cage and the sectors. During the discussions, each phase of the design, fabrication and assembly was covered in detail. Each person was asked for opinions on the adequacy of the final design and assembly. There were few suggestions for improvement as each TPC has performed well. Each person was also asked to estimate the effort necessary to provide a completed assembly.

As a result of the trip, the design of the STAR TPC will be changed where possible to closely correspond to the ALEPH design. The cost estimate will also be modified based upon their experience and their estimates of labor and fabrication costs.

Micheal Bastette described a cooling water system that prevents leakage. His system operates below atmospheric pressure and is limited to a pressure drop of about 400 mbars. This system may be used in the STAR TPC or other subsystems.

Detailed notes

General

These notes are presented in the order the discussions took place. They will serve as a trip report and as a memo to members of the STAR staff, therefore, they are in some detail.

Feb. 13

Hans Hilke, Head of DELPHI TPC

Glass masks instead of mylar were recommended for photolithography of pads. The DEPHI pads were received with some distortion due to a mylar mask being used. A glass master had been provided, but the company made a mylar copy and used it for the final fabrication.

The DELPHI pad plane support structures were made from G10 ribs. The structure was constructed on a flat marble surface. Original measurements indicated a flatness < 10 um, but later it was determined that a slight bow existed in some of the assemblies. This was removed when the assembly was bolted to the pad plane support frame. The frames were assembled at room temperature using no thermosetting glue. The wires were glued to the supports using an IR lamp for localized heating. The operating temperature is 26° C (80° F).

The front-end electronics were placed on a laminate of G-10 and aluminum. The aluminum backing is larger than the G-10 which leaves the ends exposed. These exposed ends are pushed into slots that have springs which hold the aluminum against an aluminum channel piece. A water-cooled plate is attached to this piece. The power to be removed is about 40 mW/channel. Hans emphasized the importance of considering the heat transfer problem early in the design.

The DELPHI TPC has an "embedded" ion source for amplitude calibration. In addition, laser beams were used for calibration during testing.

Henrik Foeth, DELPHI TPC assembly

During assembly of the sectors, a comb with teeth was used to hold the wires in position over the pads. The wires were strung onto a fixture, then brought down over the pad planes. The height and spacing of the wires were set by the comb teeth. This comb was fabricated by making depressions at the edge of a thin stainless steel plate. Machining was attempted, but it was not as successful as the edge deforming technique.

There is a "guard" below the cathode wire. The spacing on the gating wires is 1 mm.

The area of the TPC pads were kept the same, but the widths changed with radius. The radius lines do not point at the center, but cross away from the center. This is to ensure a straight track does not pass without a signal being obtained.

Via holes are used to make the connection from the pads through the G-10. These were filled with epoxy after fabrication was completed. The area around the vias were countersunk to obtain better plating of the copper through the G-10. The pad plane, support and electronics are inside the gas envelope. To attach the gating wires, every other one was lifted by a small pc board and the remaining ones were soldered by hand. The board was then lowered, attached to the wire support and the remaining wires were soldered. The voltage on the gate wires is 180 V. Cooling is by deionized water. A temperature gradient of about 2° C exists between the top and bottom of the TPC.

Theodolites are used for alignment tasks. The most important alignment task is to set the Z axis of the TPC parallel with the magnetic field. The X and Y positions are not as critical. Four targets on the back of each sector provide realignment capability as it is moved back into place on the support wheel.

The installation and cable connections took about 6 weeks, 3 shifts per day and 8 people. The installation and alignment took less than a week.

The DELPHI TPC has operated for about 3 years and entry has not been required. Amplifiers have been replaced, and today * is thought that there are about 1% dead channels.

Werner Witzeling, Installation and testing of ALEPH TPC

Prior to installation, the TPC was placed on a stand and tested using lasers and cosmic rays (l ray/min/cm2). The background signals (few 10 uA) due to the cosmic rays must be accounted for. It is also found that high humidity can cause about 10 nA background current. Dust appeared to be a problem and Werner said that blowing the parts with gas did not seem to solve the problem.

Assembly of the TPC started in December of 1986 and operation began in the fall of 1988. This corresponds to about 1.5 years to assemble and test. There was some waiting for sectors to arrive from Munich. One test performed was sweeping an ion source over the sectors to determine the gas gain. The gas gain spread was found to be small. Two spares/sector type were made (6 total). There is some breakdown at the edges of the chamber where the wires are at a steep angle with the support frame. They felt this is probably caused by dust.

The parallelism between the two end planes, the central membrane, and the height between the sectors are all held by machine tolerances. There are no adjustments available. The wheel was checked at the factory with a CERN representative present. The sectors had one close fitting alignment pin hole and one slotted to allow some radial movement. Alignment in the experimental hall is done by the use of theodolites. The final alignment and pad plane locations are determined using particle tracks.

The changing of a sector consists of about 2 hours of cable removal, about 4-5 hours are required to remove the sector using a special tool and the same amount of time to reinstall and reconnect the cables. They felt about 24 hours for a sector change was sufficient. They have changed 2-3 sectors and have worked on the field cage once. One of the removed sectors failed during a high voltage check, but the reason for the other failures could not be found. The removal tool was found to be too flexible, therefore, the four targets are used to adjust the position when pulling the sector up against the wheel.

It was felt that the design of the field cage is correct. The spacing of the copper strips on the non-gas side could be increased to about 3 mm. The total mylar thickness was sized for a much higher voltage than the present operating value. The inner field cage has a thinner insulation layer (3 mm). Since there is was less area, it was felt that there is less chance for breakdown. During the production of the mylar insulator layers, they had a problem with bubbles in one area due to incorrect mixing of the adhesive. An automatic mixer is considered a necessity.

The kapton/copper strips sheets were 29 cm wide. They were aligned on the mandrel by using theodolites looking at precision holes in the kapton.

Feb. 14

Wolfgang Rictner, Design, installation and test of the ALEPH TPC

The TPC was placed on a test stand which is also used to install it in the detector. They had a problem seeing the back of the sectors due to the large amount of electronics and cables. They designed and fabricated several tools to check the alignment, but did not use them. The accuracy of transfer of fiducials using other tools was felt to be about 200 um. The wheel was checked by use of three targets and a theodolite. The twist of the wheels was measured to be about 0.5 mm.

Machine tolerances were specified that held the fit between the field cages and wheel and ensured parallelism between the two pad planes and the central membrane. The central membrane is only attached at the outside radius. It is aligned to the copper strips. The inner field cage was inserted after the two end plates were installed.

The design started in 1982 and the TPC was installed in 1988. Many of the parts were made from sketches made by Wolfgang who worked on the machine for the full 6 years. He also had one designer making assembly drawings. It took about 0.5 years to assemble the TPC onto the test stand and then about 1.5 years of testing was done. Test laser beams, different from the permanently installed ones, were used for checkout and calibration.

Prior to installation of the TPC, rails were inserted into the detector. These were guided by strong wheels that allowed adjustment for the end dropping as the rails were inserted. These rails weighed 322 kg. The test stand had matching rails that allowed the TPC to be rolled into the detector. The weight at the time of installation was estimated to be 3 tons. This weight was as follows; 36 sectors at 35 kg = 1260 kg, outer field cage 900 kg, wheels (two) 500 kg for a total of 2660 kg or about 3 tons.

About 5 years and 6-8 people were required to design, fabricate and test the 36 plus 6 spare sectors. If they were to do it again, Wolfgang felt it would take about 4 years to do the same tasks without the test time.

A laser is needed on the test stand as well as cooling equipment. Temperature distributions measured on the test stand are not valid due to the different flow conditions in the detector.

Production of the outer field cage lasted about 1.5 years and the end plates (wheels) about 1 year. The design sequence was first the field cages, the end plates, the support feet, the splitters, the laser, special tools and then the checking tools. These checking tools were accurate to about 200 um. They had one full time engineer for about 5 years to do the detector interface coordination. Wolfgang felt this person must be there at the start of the design. The end plates were cast aluminum as it was assumed that this type of fabrication would provide a very stable part. The sector design was discussed and agreed upon during collaboration meetings.

If another TPC were to be designed, they would do it the same way except possibly adjust the voltage in the last few copper strips to change the voltage level near the wires. They would also pay more attention to the cooling problem and bring water to the hot spots. They would try to hold the temperature to within 0.2° C. Wolfgang estimated the heat load to be 2.5 kW/end plate or about 140 W/sector. The estimated power/channel is 100 mW.

Design of the sector removal tool was attempted for 8 months by a designer who did not complete the task. Wolfgang then spent several months on a new design with the first iteration being inadequate. He continued for 2 more months with this final design being fabricated and it is now in use.

They had no formal reviews and no safety notes were required. The designs were discussed during collaboration meetings and this served as a renew.

Micheal Bastette, Designer of a "leakless" cooling system

The system uses the concept of a barometer, but the gas volume at the top is connected to a pump. If a leak occurs, the pump removes the air as it enters the top envelope. If the ratio of pump on to off time is measured and the pumping speed is known, then the leak rate can be determined. If this is increasing with time, then a repair date can be planned. With the lowest point in the system open to the atmosphere, a negative pressure bias is placed on all parts of the cooling system. All leaks will result in air coming into the system instead of water leaking out.

The lowest pressure in his system is at the heat exchanger input. The pressure drop across the system may be about 300 mbars. Since the pressure difference between the flow channels and the outside atmosphere is small and negative, one can use thin-walled flow channels. Only the edges of such exchangers need be sealed as the external pressure holds the sandwich flat.

Mike Price, Field cage designer for ALEPH TPC

The thickness of the mylar on the outer field cage is 4 mm. The glue is more conductive than the mylar, therefore, the current goes through the glue. The glue used for the inner and outer cage assembly was a polyurethane type called Hexcellite. The bond thickness was about 20 um. The aluminum strips are 200 mm wide and 0.1 mm thick. The same machine was used for winding the copper strips, the mylar, the aluminum skins and the honeycomb. The completed structure sagged <1 mm and will not fail at 60 mbar.

The mandrel is in two pieces. It is held and rotated on large bearings at each end. There is a keyway along the length to provide room for a hold-down piece for the kapton/copper strip sheets and to assist in mandrel removal. Mike mentioned that DELPHI personnel were going to use brine to cool their mandrel down, but instead wound string on the mandrel. After fabrication, the string was pulled out which left a gap between the mandrel and the inside of the field cage. ALEPH used Tedlar, a thin TFE over the mandrel to serve as a mold release.

They found that 250 mm wide kapton/copper was hard to move during assembly. The width that seemed to be the best was 200 mm. In order to keep the copper strips straight, a straight line was put into the kapton prior to the copper being deposited. This line was made by laying the kapton on a long table and stretching a string along one edge. By aiming a laser at the string, a pattern could be seen and a small hole was punched in the pattern center. These holes were later enlarged and served as fiducials for the strip templates. These templates had to be moved down the kapton since the photolithography machine could only do about 1 m at a time. The edge of the delivered kapton was not straight enough to use as a guide.

After the copper strips were etched onto the kapton, the sheets could be placed over the mandrel. It was necessary to overlap the kapton to ensure field continuity. The last copper strip on the gas side was etched away on one piece and the copper strip on the back side, (away from the gas) was etched away on the piece to be placed next. A small hole was etched in the last strip on the gas side so the edge of the overlapped strip could be seen through the kapton. A theodolite was used to look at this edge to check the alignment. This theodolite looked through holes in a bar that were accurately machined at the proper distance apart. A laser looked at the side of the theodolite to ensure a 90° angle between the sight and the cylinder. The edges of the kapton/copper strips were taped and 200 mm wide mylar was then wound over them with a 1 mm gap. The aluminum was wound the same as the mylar. It was found that anodized aluminum was better for gluing. Apparently the DELPHI TPC used anodized aluminum for all the windings, but the ALEPH TPC only used in for the aluminum next to the honeycomb. The honeycomb was wound onto the inner aluminum skin by laying it on a long table with one end under the cylinder. Stubs held onto the honeycomb and as the cylinder rotated, the honeycomb was pulled off the table onto the cylinder. Mylar was wrapped over the honeycomb until the glue had dried.

The material being wound was fed from a bobbin. A pneumatic cylinder applied force (about 1 kg/cm) to a roller over which the material rolled. This roller pushed against the cylinder. A servo system system was used to keep the proper tension in the material being wound. Several trials were required before the tension and the roller force were correct. Scrapers were used to remove the excess glue. The limit for winding was 6 layers of mylar per day as the glue/mylar became too soft. Each layer was wound starting away from the final "good" section. It was found that * was very important to keep the humidity to < 40% for proper glue performance. Also, a relatively clean room is recommended. initially the glue was mixed by hand, but due to improper proportions occurring, an automatic mixer was designed and installed. All the components for this mixer were commercial items. One suggestion to get a precision mandrel is to glue "hard" foam over the metal and then machine the foam. Wires can be placed in the foam so it could be removed after the winding is complete.

Since the end aluminum flange inside diameter was slightly larger than the wound inner aluminum skin, spacers were placed between the flange and the skin. Glue, which filled the spaces, was injected through holes in the flange . The length of the flange was chosen by considering the stress due to a moment around the cylinder edge. When the calculated stress fell to a low value, the length was set. The central membrane is only held by the outer field cage. It was reinforced at the outer and inner radius by an additional 25 um thick layer. The mylar was placed on a large table and the center hole was cut. The conducting paint was rolled on and buffed which removed the high spots and improved the conductivity.

It was estimated that the mandrel and winding machine cost about 0.25 M (SF).

The resisters used in the field cage chains were thermally cycled until their resistances were stable. The high voltage cable insulator material was from Raychem. Copies were made of the insulator specifications.

Conclusions and recommendations

The effort saved in design and fabrication of the STAR TPC should return the cost of this trip many times over. By discussing the fabrication techniques and problems with CERN personnel a much better understanding of the complexity of the project has been gained. Most of the procedures that were discussed can be used almost as described for fabrication of the STAR TPC.

As additional personnel join the STAR TPC staff, they should visit CERN and spend time discussing specific designs and tasks. In particular, the engineer that will have the responsibility for the fabrication of the outer field cage and the sectors should visit both CERN and Munich (Sector fabrication site).

Itinerary

Leave San Francisco, CA, 11 Feb., 1992
Arrive Geneva, Switzerland, 12 Feb., 1992
Discussions with CERN personnel, 13-14 Feb., 1992
Leave Geneva, 15 Feb., 1992
Arrive San Francisco, CA, 15 Feb. 1992

Documents received

ALEPH Technical Report, CERN/LEPC/83-2, LEPC/Pl, 15 May, 1983.
ALEPH Status Report, CERN/LEPC/84-15, LEPC/M50, 10 Sept. 1984.