CLIC PRAL min workshop (Compact Linear Collider PRe ALignment min workshop)
James T Volk
April 6, 2009

This workshop was held at CERN April 2nd and 3rd 2009. Jean Pierre Quesnel was the host. The intent was to gather the world's experts on Hydrostatic Level Systems (HLS) and Wire Position Systems (WPS) to explore the state of the art of these systems, where they are currently in use, and what calibrations are done and how these systems can be applied to future $e^+ e^-$ colliders such as CLIC or the International Linear Collider (ILC). There were a total of 14 people from outside of CERN and 17 people from CERN. With the exception of BINP this constitutes the entire collection of accelerator HLS and WPS experts.

Jean Pierre Delahaye opened the workshop with a description of the need for an electron positron collider of the 0.5 to 3 TeV energy range and a brief introduction to the parameters of CLIC. Both the CLIC and ILC designs call for beams of nano meter dimensions in the vertical and horizontal planes, very small emmittances and high luminosity. The designs of both machines call for Linacs that are kilometers long with tens of thousands of magnets and RF cavities. These are challenging parameters for the alignment community to achieve. Beam based alignment will play a major role in making either machine work, but he accelerator components must start out with very good initial alignment and be monitored during operation. Movement of components due to natural effects such as earth tides and earth quakes and cultural effects such a vibrations caused by motors have to be understood and corrected for during operation. Active adjustment of components both in feedback and feed forward systems will be used. HLS and WPS will be integral part of these machines.

Daniel Schulte of CERN spoke on the accuracy of alignment criterion for CLIC. He covered such things as BPM offsets, quad alignment tolerances and RF cavity tolerances. Many of these numbers can be found in CLIC design reports. The fundamental fact is that the necessary tolerances required before beam can be introduced into either the ILC or CLIC are on the order of 10 micro meters, this is a factor of ten better than currently achievable alignment techniques! The accelerator alignment community is willing to rise to this challenge.

Jean Pierre Quesnel presented CLIC pre alignment base line for the Main Linac and beam delivery system. His main points are:

1. The need to upgrade alignment accuracy by a factor of 30
2. Have a cost evaluation and integrated solutions by 2010 for CLIC
3. The need to use existing technology
4. Study the CERN baseline for LHC and learn from other labs
5. Improve HLS and WPS sensors and use techniques from other labs.

CERN has used WPS for over 30 years to set straight lines; the entire LHC was aligned with WPS and laser trackers. This system works well as was confirmed last September when beam was successfully circulated around the entire LHC with minimal corrector magnets use and no need to adjust magnet positions. WPS and HLS systems are in use on the low beta quads at all four major interaction regions in addition both ATLAS and CMS have HLS system monitoring the motion of the detectors. They use Fogale HLS sensors and pickups for the WPS systems. There is a great deal of experience in both systems at CERN.

Hélène Mainaud Durand presented the CLIC survey and alignment strategy being developed at CERN. The criterions are:

1. Mechanical pre alignment ±0.1 mm at 1 σ
2. Active alignment ±10 micro meter at 3 σ
3. Beam based alignment on the micro meter level
4. Beam based feedback on the nanometer level

There will be a surface network that has to be transferred into the tunnel to set a local network then WPS wires of 200 meter length will be used to set the offsets. There will be overlapping wires to reduce the errors in linking the girders that support the quads and RF cavities. There will be the need to understand the shape of the wire to the micrometer level and to account for effects of variation in gravity along the length of the machine. There are several test facilities at CERN working on these problems.

Andreas Herty of CERN spoke on calibration of the HLS systems. There are eight straight sections; four of them have major interaction regions. There are both HLS and WPS systems linking the low beta quads on either side of the detectors in these 4 regions. There are a total of 112 HLS sensors, 60 WPS systems and 24 distances offset sensors (DOMS) in use. They use Fogale HLS and WPS sensors in all cases. Due to EU rules all equipment that is exposed to radiation has to be tracked. This makes it very difficult to ship any sensor back to Fogale for repair or calibration. The decision was made to develop repair and calibration facilities at CERN.

They do an initial check out of sensors when they are received from Fogale that includes check of linearity and range. They have determined that the capacitive HLS sensors have a 2-day warm up time to stabilize the readouts. For the WPS sensors there is a 3-hour warm up time to stabilize.

There is a radiation exposure test program in place. At LHC they expect to have 16 kiloGrays per year in the low beta regions. Various sensors are exposed to ^{60}Co source to see what integrated dose will do to the electronics and capacitive sensors. There was some discussion about using ^{60}Co as a realistic source of particles in that there would be neutrons, gammas, and electrons in the mix of particles generated at the LHC.

They test the electronics and sensors separately, the sensors are OK to 160 kiloGrays and the electronics can stand 500 Grays. This indicates the need to have the electronics remote from the sensors and protected by shielding

There is also testing in magnetic fields. This is important due to the unexpected and large stray fields from CMS. The Fogale sensors are good to 0.03 Tesla this is more than any measured stray fields. The problems that do occur are due to dust in the optical sensors.

Friedrich Lackner of CERN spoke on optical WPS. CERN and Brandies University have been developing BCAM and Resnik systems for monitoring detector positions on ATLAS and for monitoring WPS wire positions. For the WPS work they use two CCD cameras at a 30-degree angle with overlapping fields of view to pick up the wire position. A Vectraum wire is used this is a mono filament wire there still is a long term stretching issue that is being explored. The cost is $400 per channel and they can monitor multiple wires at once. This is important for over lapping wire systems.

Thomas Touzé spoke on the TT1 test facility. This is a 200-meter long tunnel that was used to transport beam from the PS to the ISR. The temperature is stable to 0.5 C making it ideal to study long-term drift of WPS and HLS systems. There are 3 WPS systems one 200 meters long, one 140 meters long and one 50 meters long the last two overlap by 10 meters. Optical WPS sensors are used. In addition there is a Fogale HLS system monitoring the WPS stands. There is also a Resnik system that is not in use at this time. We did tour the TT1 facility on Friday, April 3. They believe that accuracies of 5 micrometers are possible they have not yet achieved this. Humidity and long term stretching are problems. There are also the questions of what the exact shape of the wire is on the micrometer level. Does a 200-meter long wire hang in a catenary at the micron level?

After lunch **David Martin** of ESRF spoke on the systems at Grenoble. On the light source there are 18 single axis WPS systems monitoring each girder there are 4 biaxial WPS for calibrations systems. They have also used HLS on each girder for active re alignment of the light source since 1990. The ESRF is at the junction of two rivers the machine is sensitive to the rise and fall of the rivers also the flushing of slit and sediments from behind a nearby dam that occurs every spring. They have monitored the movement of the site over time and have built a very good calibration bench for both HLS and WPS systems.

Errors can be divided into two types:

A. Statistical errors

B. All other errors

There is the need to establish uncertainties and then link these to the calibration systems. The type A errors can be determined through classical survey methods and dominate the total error. All of these errors are then added in quadrature.

Alan Lestrade from SOLEIL discussed the HLS and WPS system in use there. SOLEIL has 160 quads on 56 girders in 24 sections. The machine has a 354-meter circumference and the floor is 2 to 3 meters thick. They have used HLS to monitor one of the floor slabs for a year and have seen changes on the order of 5 micro meters but no twisting in the slab. They calibrate their HLS systems using stainless steel gauge blocks. The HLS data is corrected for temperature effects that are water expansion due to changes in temperature. They do regular filling tests of the system to calibrate linearity and have determined their system has an impedance time of 3 hours.

Karsten Dreyer of PSI the Swiss light source described their systems. They use a capacitive HLS with a ½ filled pipe the sensors are manufactured by EDI Mejer. The resolution is better than 2 micrometers. There are 4 HLS sensors per girder with a settling time of 15 minutes after filling. This system is used for monitoring long term drifts of the machine there is no absolute reference. They have an automatic water filling system. The system was installed in 2000 and became operational in 2003.

Fuqiuang Wei of PSI is looking at 4 girders at a time over the 12 sections for a difference in two sensors 92 meters apart he sees a 12.4-hour change of 7 micrometers due to earth tides. I see the same motion for the MINOS HLS sensors 90 meter apart.

Next **Markus Schlösser** and **Johannes Prenting** of DESY spoke on their HLS and WPS work. Markus has been developing ultra sonic HLS for several years. The system is built around the GE Ultrasonic transponder and uses an internal calibration pillar similar to the BINP system. The pillar has a step in it so that an ultra sonic pulse reflects off the bottom, the step and the water surface. This allows for calculation of the speed of sound in water for each measurement eliminating the error caused by the temperature variation affecting the speed of sound.

The pools, pillar and transponder are all stainless steel. They have been experiencing problems with corrosion of the transponders and pillars. The cause is electrolysis caused by different elements in particular the solder used in the transponder case has changed from a lead based solder to something else. Markus has measured significant voltages between two sensors in a pool of water. This voltage is the cause of the corrosion.

To solve this problem they are isolating the transponder from the water and changing the pillar from stainless steel to quartz. There is no longer a corrosion problem but the pillar is much more delicate. I am very concerned about this having just started using BINP ultra sonic HLS. I will inspect my systems for corrosion. One of the differences in our systems is I use distilled water while they put an anti fugal agent in their water. Markus also claims to have calcium in his distilled water where I do not have this sort of problem.

For PETRA 3 there are 34 girders with 4 ultra sonic sensors on each girder they do not plan on active alignment of the machine. There are also HLS sensors in the experimental hall for a total of 160 ultra sonic sensors taking data at a one-minute repetition rate. PERTA 3 is schedule to start running next week.

Johannes spoke on WPS for the XFEL now under construction at DESY. There will be a WPS system used in the 300-meter long free electron laser, this will be with Fogale sensors and will also have corner cubes to obtain an absolute alignment of the system. There will be a laser and optical slit with a moving stage to locate the wire position. This will tie into the survey plate again to obtain an absolute alignment. They are still working on getting this system up and running so there is no data available.

The other system in use is a laser in an evacuated tube to set a straight line for offset measurements. Targets are arranged down the line and the dispersion patterns from the targets are monitored in CCD cameras to calculate the offsets. The idea is in the tunnel there will be a pipe with targets along the length that laser trackers could use to determine their positions for alignment of accelerator components.

Mika Masuzawa from KEK addressed their issues. There are a few HLS sensors along the JPARC Linac and in the synchrotron. The ground at JPARC is difficult, they are located on the shore of the Pacific Ocean over an ancient riverbed. There is significant ground shifting due to underground water movement and waves on the shore. They are using Tygon tubing for their HLS systems and have to add water every 6 months. (I had to discover for myself that Tygon absorbs water at a fantastic rate and is not suitable for HLS work.) She did express interest n the Tevatron style HLS due to its low cost and stability. We had extensive discussion after the meeting regarding the Fermi system.

J Volk the Fermilab HLS experience. I presented a report on the various systems in use at Fermilab including the Tevatron low beta HLS the 204 HLS sensors on the quads in the Tevatron as well as work in MINOS and LaFarge mine for ILC studies and the new installation of Tevatron HLS at the Homestake mine in Lead South Dakota for DUSEL work. My talk can be found at http://home.fnal.gov/~volk/CERN/HLS-WPS-WRKSHP/

Georg Gassner and **Robert Ruland** of SLAC presented their HLS and WPS work for LCLS and SPEAR. HLS systems have been in use at SLAC for many years. They have a long relation with BINP and all HLS sensors are purchased from Budker.

For the LCLS there will be 136 HLS sensors 4 on each girder, one ultrasonic and 3 capacitive sensors all linked with a ½ fill pipe. The ultrasonic sensors have a target nest to receive a 1.5 inch retro reflector allowing for a tie in with outside survey networks and hence an absolute elevation measurement. The requirements are 0.1-micrometer precision with an accuracy of 0.1% of full range. The long-term drift of the system is yet to be measured.

Their WPS systems are inductive sensors originally developed by Zack Wollf of SLAC. The system has a one-micrometer resolution. A WPS will also be used for LCLS to align the undulators. The system will have a resolution of 100 nanometers with a 100-nanometer drift per day. It uses a 104-meter long gold plated stainless steel wire; the sage is 140 mm and an RF frequency of 140 megahertz. There is a 10 micrometer vertical oscillation in the wire they solve this problem by averaging 5 to 10 samples for each measurement.

SPEAR 3 will have 33 HLS sensors over the 330-meter circumference. This machine is built on the surface. There is clear day night variations in elevation due to solar heating 200-micrometer shifts of elevation over a one-month period are normal. Ten to twenty micrometer elevation changes are seen from day to night.

Xiao-Ye He of NSRL in China spoke about all the systems in use at the various light sources and accelerators in China. They use a different technique for HLS. A glass bowl is floated on the water pool with a vertical rod. A laser shines on the marked rod and reflected light is read by CCD camera to determine the movement of the water. There is a careful and extensive calibration procedure for each sensor. There are four sensors per girder at BEPC II. They use a combination of ½ filled and fully filled water pipes. There are fully filled U's with air by passes to go around various obstacles in the water path. The measurement range is ±5mm with a repeatability of 0.05 micrometers and a linearity of 0.05% of full scale. They are in the process of instrumenting the entire system.

Friday morning consisted of tours of CMS both in the detector hall and the tunnel just outside of the detector hall. The low beta quads at LHC are instrumented with both HLS and WPS. There is an external survey gallery that runs to the radial inside of the accelerator tunnel that carries the water pipe for the HLS system and the wire for the WPS system. They use Fogale HLS systems and a ½ filled pipe. Due to the slope of the LHC there is a 40 cm step in the system with stacked HLS sensors at that point. The WPS has 16-meter long invar rods that are tied to each end of each low beta quad and the wire sensor in the survey gallery. The wire extends from one end to the other of the low beta system through the experimental hall. The wire is protected by aluminum covers but still there are problems at times with experimenters hitting the covers or even worse attaching cables and other items to these covers.

After the LHC tour we went to TT1 to see the WPS stability test system that Thomas Touze has setup.

Friday afternoon was a large group discussion of calibration techniques for both HLS and WPS systems. Linearity and absolute measurement techniques were discussed. Also Dominique Missiaen of CERN is creating a list of all HLS and WPS system and calibration benches. There is a desire to do radiation testing of various components in both HLS and WPS systems to generate a table of standards. CERN has the capacity to do radiation exposures of various particle types and fluxes.