TECHNIQUES USED IN THE ALIGNMENT OF TJNAF'S ACCELERATORS AND EXPERIMENTAL HALLS*

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1. INTRODUCTION

With the successful completion of the main accelerator in 1994 the alignment emphasis at the Thomas Jefferson National Accelerator Facility (formerly CEBAF) switched to the continuing installation and upgrades in the three experimental halls. This presentation examines the techniques used in completing the CEBAF machine and also gives an update on the alignment of the new accelerator, a 1 kW free-electron laser, currently being built at the facility.

2. CEBAF ACCELERATOR MAINTENANCE AND MONITORING

After the delivery of first beam to Hall C in July 1994 much of the alignment activity shifted to the experimental Halls. Although completion of a five pass 4 Gev machine took almost another year, survey activity in the main accelerator was mostly confined to maintenance and minor upgrades. One exception to this was the monitoring activities in the south linac which, it was hoped, would shed some light on the path length changes experienced in the machine. These changes manifested themselves in the frequent field and positional changes needed in the dogleg magnets. These magnets were designed to adjust for changes in the apparent length of the machine by varying the magnetic field and corresponding pathlength through the magnet. It was noticed that an annual oscillation in the apparent pathlength was occurring.

In an effort to understand what was happening in the machine several distances were chosen in the south linac which could be monitored on a regular basis during shut down periods. Measurements began in October 1995 and were made with a Kern ME5000 mekometer which has an accuracy of 0.2mm + 0.2ppm (as per manufacturer). Up to six distances were measured between standard survey monuments grouted into the tunnel floor. The distances ranged from 297 meters to 362 meters.

Analysis of the results revealed that a small seasonal fluctuation could be identified, with the winter measurements being generally longer than those made in summer. The maximum dimensional change was less than 1.5mm between consecutive measurements, with the average being about 0.6mm. Average air temperatures (in the tunnel) recorded at the time of the measurements did not vary significantly. Unfortunately this did not compare well with the data

observed during machine operations. This data showed the pathlength decreasing in [1]winter/spring by an average of 5mm, which is neither the right direction nor the right magnitude.
However, the results have been useful in eliminating tunnel movements as a possible cause of the pathlength oscillations.

3. HALL A SPECTROMETER POINTING SURVEYS

Hall A is the largest of the three experimental Halls at Jefferson Lab. It contains two identical High Resolution Spectrometers (electron and hadron) in a Quad : Quad : Dipole : Quad arrangement mounted to a rigid "box beam". During each experiment in the hall, the spectrometers are moved frequently to different angles. Each move has the potential to change the pointing to the target by several millimeters. Ultimately an automated alignment system is planned. However, this was not available for the first experimental run between May and July of this year. For this experiment (89003) a total of twenty angle changes were planned, three for the electron spectrometer, and seventeen for the hadron. The angle of the spectrometers had to be known to better than 0.5mrad, and to achieve reasonable acceptance, the pointing had to be better than 3mm.

Since the optical elements of the spectrometer were all linked by the box beam, it was determined that to best characterize the angle, mis-pointing, pitch and roll of the spectrometers a survey of only the dipole and box beam fiducials would be required. Typically this would be carried out using the Stanford Industrial Measurement System (SIMS) to survey the fiducials in the Hall coordinate system, the data would then be processed in the office using a seven parameter transformation defining the center line of the spectrometer, which would then be analyzed to determine the alignment characteristics. This whole process would take approximately 4 hours.

A software package was developed which expanded the capability of the existing SIMS package. This included a more user friendly control file/initialization element, which allowed graphical selection of control and fiducial points. An error snooping element was also developed allowing inspection of large residuals. A seven parameter transformation was performed in the field, and automated analysis of the output allowed the decision whether to adjust the spectrometer alignment and pointing to be made.

This approach, whilst not introducing anything significantly new into the process, enabled the various elements of it to be tied together in a single, more streamlined system. A time reduction of over 2 hours from initial set up to final results was realized. Also, the new system enabled Physics staff to carry out the surveys whilst maintaining consistency of results.

4. HALL B ALIGNMENT ACTIVIES WITH SPECIAL REFERENCE TO REGION 3

Hall B was the last of the 3 halls to be completed with first beam to the hall in December of 1996, commissioning in February 1997, and first data taking in August of 1997. Hall B houses the

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CEBAF Large Acceptance Spectrometer (CLAS) which is used to measure the induced reaction of electrons and photons. The main magnet (Torus) is comprised of 6 superconducting coils in a toroidal arrangement, which is suspended from an overhead I-beam. The charged particles in CLAS are tracked by drift chambers arranged in three layered regions and supported by the Torus. Each of the 3 regions is comprised of 6 sectors. Region 1 is located closest to the target within the almost field free region inside the Torus bore, and is used to determine the initial direction. Farther out, Region 2 is located between the Torus coils, in the region of strong toroidal magnetic field, and is used to obtain a second measurement of the particle track at a point where the curvature is maximal, to achieve the best energy resolution. Region 3 is located outside the coils, in a region of low magnetic field, and measures the final direction as the charged particles head towards the outer Time-of-Flight counters, Cerenkov counters and the Electromagnetic Calorimeters. These counters are mounted independently on large moveable carriages roughly 14 meters high and weighing between 120 to 200 tons.

The survey and installation of the 6 Region 3 drift chambers was one of over 20 main alignment activities in the Hall. A box layup fixture (jig) was constructed in a secondary building to facilitate the construction of each drift chamber, and serve as the basis for the coordinate system for each Region 3 chamber. The purpose of the jig fixture was to hold the two endplates of the drift chamber in a stable position while carbon fiber posts and a carbon fiber shell were placed and glued into position. Each end plate holds one end of 20 000 detector wires for each chamber. The goal in aligning the end plates was to assist the software group in determining the location of each wire (120,000 wires in region 3 alone) when installed in the hall.

Hall B engineers originally hoped that the fixture (an approximate volume of 50 cubic meters) could be aligned to less than 0.1 millimeter. After initial attempts it was realized the adjustment system could not achieve the required tolerance. A small control network was set up around the fixture to control the scale over the length of the jig and then SIMS was used along with a seven parameter transformation to align the jig. A typical survey would require 10 theodolite positions and on average about 250 observations. A final standard error (average) for the 14 control fiducials on the jig of 0.22 mm (square sum of the errors dZ, dX, dY) was achieved, with a standard deviation of 0.10mm.

The only portion of the chamber that would be visible when final installation took place was the carbon fiber shell, but this could not be seen during assembly in the layup fixture. A two part survey was devised where coordinates were established on the edge of the chamber while in the jig, with the second survey of the chamber carried out in the clean room where the wires were strung. While in the clean room the chambers were rotated into a vertical position such that the carbon fiber shell was accessible. SIMS was again used to coordinate targets on this shell. After installation, the final position of each chamber was surveyed relative to the Torus' magnetic center. Since there was no direct line of sight between the Torus and the Region 3 fiducials this part of the survey was again carried out in two parts. SIMS surveys were used to locate the magnet relative to the hall control network, and, finally, to locate the Region 3 targets from visible control monuments.

Although no new alignment techniques were employed in carrying out this alignment task, the complexity of the problem made it unique and interesting. An estimated final error for the drift chamber control targets was calculated using the standard errors from the 4 surveys along with the accompanying transformations. Using the average root mean square error per point for each survey and transformation, and then again taking the RMS value for the individual surveys and transformations, resulted in a value of approximately $\pm$ 0.75 mm. This number should be considered only as a best estimate of the overall final accuracy of the coordinates relative to the magnet coordinate system.

5. MAGNETIC CENTERLINE MEASUREMENTS USING A COLLOIDAL IRON SOLUTION

The application of colloidal targeting has been used at several labs around the world [1], and has proven to be a simple yet accurate means of locating the magnetic centerline of quadrupoles. At Jefferson lab. this technique has been the primary means used to map the magnetic centerline of the large superconducting quadrupoles in Halls A and C. Temple University provided assembly and installation of the mapper while Jefferson Lab was responsible for the survey and alignment.

The setup consists of two polarizers, a light source and a target mounted on rails allowing it to be moved longitudinally along the magnet centerline. The target is a colloidal solution of iron crystallites which, when positioned in a magnetic field, forms a distinct pattern aligned to the magnetic poles. To view the target, light is polarized, then directed through the colloidal solution when the magnetic field is energized. The light passes through a second polarizer, perpendicular to the first, enabling the pattern formed by the iron crystolites to be viewed from a transit. The mapping was mostly carried out after installation due to the accessibility of the electrical and cryogenic leads.

A reference line of sight was established coincident with geometric centerline of the magnet by leveling up the quad and transferring a line parallel to the geometric centerline from the outside fiducials using an optical square. A lateral slide and precision lift allowed precise centering of the transit horizontally and vertically. A two way coordinate micrometer mounted to the transit allowed for horizontal and vertical measurements of up to + - 2.5 mm simultaneously. The polarizers and target each had secondary supports which allowed for vertical and horizontal adjustment along with pitch, yaw, and roll. The positioning was done remotely using extension rods which were attached to the supports. To set the target cell perpendicular to the magnet centerline, a light source was attached to the transit to establish autoreflection off the cell window. The polarizers were rotated and recrossed and the cell was measured a second time for repeatability.

To confirm that the coils were not shifting inside the magnet, the cell was measured at several different levels of amperage. The residuals were within 100 microns. After the magnet centerline was measured at the upstream, middle, and downstream locations, a seven parameter transformation was carried out to redefine the fiducials relative to the magnetic centerline. Final alignment onto beam centerline could then be achieved.

The overall accuracy at which the magnet centerline was related to the outside fiducials is estimated to be within 200 microns. This is based on the optical tooling setup, the resolution of the target, and the accuracy of the original fiducialization survey. When the magnets were fully energized, the resolution of the target cell was about 60 microns. This, however, was dependent on the intensity of the field and degradation occurred if the polarizers were not correctly rotated and aligned. Because the target is actually formed by the magnetic field, much of the error is limited to relating it to the geometric centerline. The accuracy quoted above is under ideal conditions with care taken during setup.

6. THE NEW FREE ELECTRON LASER PROJECT

Construction of the building for the Free Electron Laser was started in June 1996. On September 30 of this year the first beam was generated, and installation was nearing completion. When finished, towards the end of the year, the building will house a 1 kW, tunable infra red (3-6 micron) free electron laser which will demonstrate the potential of such machines for research, defense and industrial purposes.

Although the machine is not large (measuring just under 50 m end to end), it should provide a beam 100 times more powerful than any other tunable laser currently in existence. Alignment tolerances for components have been defined as 0.5mm rms for quadrupoles, and 1.0mm rms for dipoles. Linearity of entrance and exit quads to the wiggler magnet is 0.1mm.

The initial stage in the alignment took place in December 96 when a “skeleton” four point control network was established. The skeleton net was used as the basis of an as found survey carried out by an outside survey company, which defined the location of the walls, pillars, penetrations and floor elevations. This information was then used to define the full network.

Twenty-six monuments made up the full network which was measured in February 97. As in the main CEBAF machine [2], survey monuments consist of stainless steel cups drilled and grouted into the floor capable of holding a 1.5 inch diameter sphere. For the first network survey Leica TC2002 distances were used with the thought that this would provide sufficient accuracy for initial installation, and that a re-measurement would be carried out before component alignment. Error ellipses for this survey were less than 0.3mm.

A resurvey of the network was carried out in June 97 using Mekometer ME5000 distances. This resulted in error ellipses mostly below 0.1mm. It was noticed, however, that there was a significant systematic change between the two surveys equivalent to 5.0 mm over 50m expansion across the network. Check measurements were carried out including measurements with both instruments of the same lines. These confirmed the general trend. The air temperature difference between the February and June surveys was approximately 14 degrees Celsius. With the coefficient of expansion of concrete at 9.9 ppm per degree, an expansion of 6.9mm over 50m could be expected. This accounts for most of the difference observed although ground temperatures may be more influential.

7. REFERENCES

[1] M.A. Goldman, R.E. Sikora, T.J. Shea, *Preliminary studies on a magneto-optical procedure for aligning RHIC magnets.* AGS Department, Brookhaven National Laoratory.

[2] C.J. Curtis, W, Oren, K.J. Tremblay, *Survey Techniques, Developed to Align Stacked Beamlines at CEBAF*, Proceedings of the Third International Workshop on Accelerator Alignment, Annecy, France, September 1993.