7/27/87 3 ... (37) Cat. U-28 E-27203

SLAC-PUB--4141

DE87 004566

INCORPORATION OF THE KERN ECDS-PC SOFTWARE INTO A PROJECT ORIENTED SOFTWARE ENVIRONMENT*

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ABSTRACT

The Stanford Linear Accelerator Center (SLAC) is in the process of building a new particle collider, the Stanford Linear Collider (SLC). The tunnel which houses the SLC is about 3 km long and contains approximately 1000 magnets. Besides a very precise absolute positioning of these magnets, the alignment of adjacent magnet ends is of particular importance to the success of the whole project. Because of this and the limited time frame, a survey method which was not only reliable and self-checking but also fast had to be developed. Therefore, the concept of MAS (Magnet Alignment System) was developed.

This system utilizes the on-line data collection and the rigorous least-squares bundle adjustment of the KERN ECDS-PC system to fulfill these requirements. The ECDS software is embedded in a project tailored software system with modules which take care of: fixture and magnet calibration corrections, the calculation of ideal coordinates and their comparison to measured coordinates, the translation of detected misalignments into the coordinate system of the mechanical adjustments and the control of the adjustments with on-line electronic dial-gauges.

This paper gives a brief introduction to the SLC project and some of the survey problems which are unique to this machine. The basic ideas of the KERN ECDS-PC system are explained and a discussion of the practical aspects, such as targeting and set-ups are given. MAS and its modules are explained in detail.

INTRODUCTION

The Stanford Linear Accelerator Center is nearing the completion of a new single pass electron-positron collider. This machine will provide center-of-mass energies in the range of 100 GEV. What makes this machine different from traditional storage rings is that it has only a single interaction region where colliding beams have a chance to interact before being dumped. To achieve the desired luminosity at the interaction point the beams will be focused to approximately 2 square microns, after traveling through 1.4 km of bending, focusing and defocusing magnets (SLC Design Handbook 1984). Due to site restrictions, this system of steering magnets was designed to lie in multiple inclined planes which allow the beam to be steered not only around the two arcs but also up and down grades of up to 10%. This makes all six degrees of freedom of each magnet significant and inseparable.

Adding to the difficulties in aligning a machine such as this are the high absolute and relative accuracies for positioning the magnets. The most important ones to consider for this paper are relative accuracies which reflect smoothness. Two of these are:

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*Work supported by the Department of Energy, contract DE-AC03-76SF00515.

Presented at the 1987 ASP-ACSM Annual Spring Meeting,
Washington, D.C., March 26-April 3.

CONF-870379--1

DR#0120-1

- The alignment of one magnet junction relative to an adjacent one should be within 100 μm.
- The transverse offsets between adjacent magnet ends must not exceed 100 μm.

The first of these is achieved by standard surveying methods (Pietryka 1985). The second would traditionally be solved by fabricating a fixture to fit over adjacent magnet ends to simulate the desired intersection geometry. The traditional approach has been tried but has proven to be almost impossible due to manufacturing and calibration errors in both the fixtures and the magnets. Therefore, it became necessary to find a precise and self-checking way to survey the magnet ends while taking into account the different element offsets. This spawned the idea of MAS which is structured around the KERN ECDS-PC software system and attempts to automate the complete measurement routine so that both speed and accuracy can be achieved. The makeup and rational behind this system is explained here.

PROBLEM

The problem approached here is to align a particle's trajectory as it leaves a magnet, to the trajectory defined by the next magnet to within ± 100 μm in the directions transverse to the beam line. This task is complicated by several factors. The first is that magnets can be rolled up to 15° and pitched at a 10% slope, thus making all six degrees of freedom important (Oren 1985). The second factor is that the beam line can't be referenced directly. The beam tube is completely surrounded by equipment, therefore, reference grooves were stamped into the core laminations of the magnets (see Fig. 1). This forces the magnet fiducial points out 150 mm from the mechanical center line of the lamination. Finally, it was impossible to manufacture each of the 910 magnets to the same dimensions, therefore, each one has measured calibration values. These numbers reflect not only mechanical fabrication errors but also an average magnetic offset which must be accounted for when aligning the magnets.

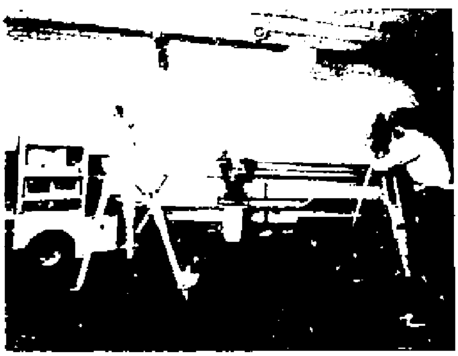

Figure 1

What had to be found was a system which would handle these difficulties and still give reliable results. It had to be repeatable and provide redundancy in the measurements. Over 900 junctions must be measured each with its own geometry as defined by the beam line and the magnet calibrations. Therefore, it not only had to be fast but [illegible] cope with the intricacies of the junction. Finally, the system m[illegible] robust enough to be taken into the field and operated by skilled technicians.

POSSIBLE SOLUTIONS

In searching for a solution to this problem one must understand what is known about the situation. In this case the ideal geometry of the magnet junction is defined by a beam simulation program called TRANSPORT (Brown 1973). TRANSPORT defines all the transformation parameters between the magnets. Any perturbations from these parameters have been measured and are contained in the magnet calibration numbers. This opens up two possibilities; the junction can be physically represented by a fixture or it can be mathematically modeled, and the differences surveyed.

FIXTURING

Building a fixture to represent the intersection geometry brings up several problems which have plagued industry for years. First, it must be built to exacting standards which make it extremely costly. Second, it must be stable to maintain its calibration as long as possible assuming that its calibration can be adjusted. Third, a way must be found to calibrate it. Finally, in this case, a method must be found to incorporate continuously changing geometry as defined by the objects being surveyed. However, if these problems can be overcome then alignment can be fast and the procedure easily understood by the field crews.

SURVEYING

Another way to solve the alignment problem is to simply adjust the magnets under the control of two theodolites whose lines of sight intersect at the proper absolute position for a fiducial mark. When this is done, the calculations for the ideal coordinates of the mark can take into account measured fixture and magnet calibration values. This solution is labor intensive and time consuming. Also, since not only the spatial location of the point is important but also the orientation angles of the magnet, two more points must be shot or the angles controlled with inclinometers. The method also implies that instruments are set up on points whose absolute coordinates are known a priori. This brings in the possibility of setup errors, and detracts from the flexibility of the system. Finally, intersections with only two theodolites are unique, so no meaningful statistics on their quality can be derived.

With all these factors in mind the KERN ECDS-PC system was looked into. The package allows one to survey in either a theodolite or object defined coordinate system (Lardelli A. 1984, 1985). This was ideal for the problem at hand, because it allowed for relative measurements rather than absolute. Its software is rigorous and provides for redundant measurements. This is done through a bundle adjustment (Manual of Photogrammetry 1980) when solving the collinearity equations for the theodolite orientation parameters (Bethel 1986). The method allows for the incorporation of fixture and magnet calibration values, like the intersections.

The system does bring some problems with it. For this task rather skilled operators are required so that a successful measurement can be carried out. It's not as fast as a fixture would be, but through careful planning it can be done in a reasonable amount of time. Also, from a production viewpoint, the system has too many options to make it practical for a strictly defined problem.

MAGNET ALIGNMENT SYSTEM OVERVIEW

To utilize the advantages of the ECDS-PC system and get around its problems, the Magnet Alignment System was designed (See Fig. 2). The idea was to automate the data flow between the ECDS software and a project-oriented software system. This menu driven system, which is described below, controls the complete measurement and adjustment phases of the project by leading the operator through the entire procedure.

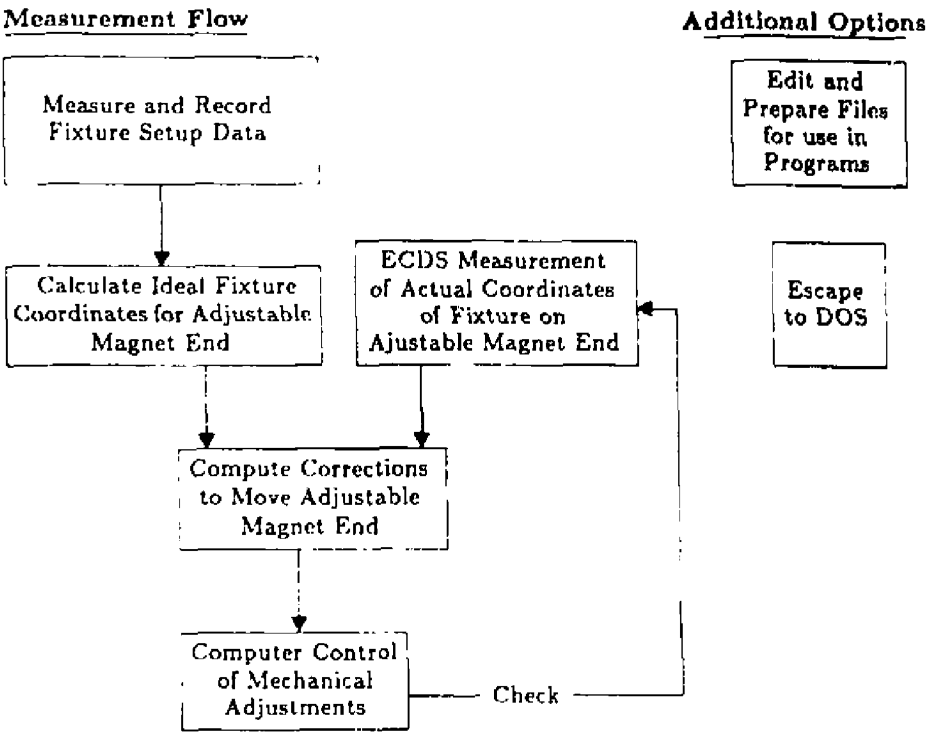

Figure 2. MAS Layout

HARDWARE

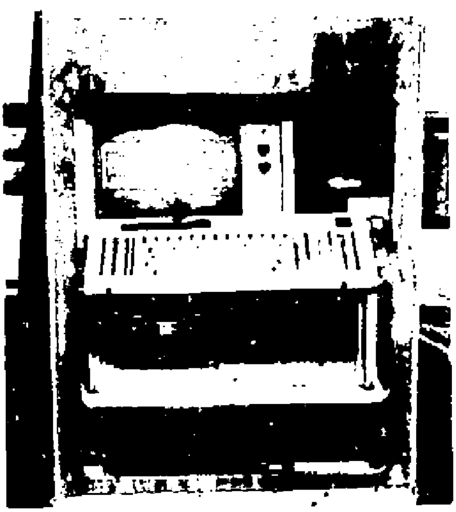

Figure 3

The basic ECDS-PC system consists of a portable IBM-PC with a 20 megabyte hard disk, two KERN E2 Theodolites, and several SLAC built interface boxes and cables (See Fig. 1). The computer and printer have been mounted on an electric cart for portability in the SLC tunnel (See Fig. 3). Other equipment such as a customized Schaevitz (Oren 1985) inclinometer and various power strips are also attached to the cart.

To round out the equipment list are two reference clamps (see Fig. 4) which mount on the grooves of the adjacent magnet ends. These durable clamps have three dowel rods which pick up the direction and position of the magnets. These dowels along with the top reference surface of the clamp define the fixture coordinate system. Each clamp is fitted with holes for 12 targets and one CERN socket. The positions of these reference marks have been measured to a few microns with a Zeiss Coordinate Measuring Machine (CMM). The holes can be fitted with either tooling balls or SLAC manufactured mounts with optical tooling targets. The clamp also has a reference surface on which to measure the roll and pitch of the clamp.

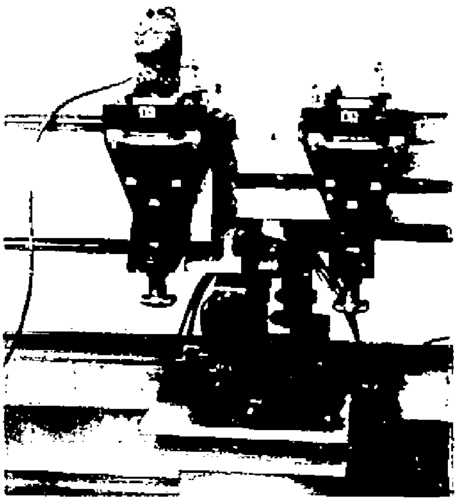

Figure 4

MASUREMENT CORE

The measurement core consists of the ECDS-PC software, whose operation has been simplified by automatically feeding it the necessary files to get the system running. This eliminates the need to go through the project description phase each new setup.

The basic philosophy behind the measurement procedure is to determine the actual relative alignment of the adjacent magnet ends and then while under the control of electronic dial gauges adjust the position of one of them so that they face one another. To do this, both theodolites are oriented to the fixed magnet end by sighting on 10–12 reference points. After the bundle adjustment, the data gathering mode is entered and coordinates for 10–12 fiducial marks on the adjustable magnet end are measured. The comparisons to the ideals are then made and the mechanical adjustments carried out.

FIXTURE SETUP DATA

This module prepares the input file for the ideal coordinate calculations of the fiducial marks on the adjustable magnet. The program prompts the user for the necessary information which includes magnet names, fixture numbers, and offsets of fixtures from the ends of the magnets. The controller for the inclinometer is directly interfaced with the PC, so the pitch and roll are entered at the touch of a button.

IDEAL COORDINATE CALCULATION

This program simulates the geometry of the magnet-to-magnet intersection and calculates ideal coordinates of the adjustable magnet end relative to the fixed end. The required input data is put together in the previous module along with fixture and magnet calibration numbers. The program then transforms this data through a series of 12 sequential rotations and six sets of shifts to give the required coordinates. This package along with the ECDS system puts a strain on the storage capacity of the PC.

COMPUTATION OF CORRECTIONS

The results of the measurements and the ideal coordinate calculations are compared here to come up with movements to be made on the adjustable magnet. This is a simple operation that only requires a subtraction and assignment of signs according to the location of the junction in the arc.

CONTROL OF MECHANICAL ADJUSTMENTS

This module is made up of several 'C' programs which read the dial gauges and inclinometers that control the adjustments. These devices are hooked through an interface box to the PC so that adjustment blunders can be checked for. The PC displays the current readings on the instruments as the operator makes the necessary movements to the magnets. If a mistake occurs the PC beeps and will not allow the setup to be broken until corrections are made. This also provides a history file of what was done to each intersection measured. This file is downloaded to a SLAC data management program called GEONET (Ruland 1986) for storage on the main alignment data base.

EDIT AND PREPARE FILES

This option allows one to skip around and prepare files for the different modules of the system. That means that although the system prompts the operator to follow a set procedure, he does not have to. He can move around within the system as long as processing is done in a logical manner.

CONCLUSION

Although MAS is a mathematically complicated system, it has successfully functioned in a hostile environment that demands both accuracy and efficiency. It has helped solve a difficult problem which is critical to this high energy physics project. This would have been much harder if traditional methods of optical tooling and fixturing were used.

REFERENCES

Bethel, J. and Sedej, J., 1986, Submarine Hull Mapping and Fixture Set-out: An Application of the ECDS System: *Proc. of the 46th ASPRS-ACSM Convention*, pp. 92–96, Washington, D.C., 1986.

Brown, K. L., Carey, D. C., Iselin, Ch. and Rothacker, F., TRANSPORT, A Computer Program for Designing Charged Particle Beam Transport Systems, SLAC-91 (1973 Rev.), NAL 91 and CERN 80-04.

Manual of Photogrammetry, Fourth Edition, 1980, pp. 88-101, Falls Church, Virginia, American Society of Photogrammetry.

Lardelli, A., 1984, ECDS1—An Electronic Coordinate Determination System for Industrial Applications, Aarau, Kern and Co., Ltd.

Lardelli, A., 1985, A Mobile 3D—Measuring System—the New Standard for Metrology and Quality Control, Aarau, Kern and Co., Ltd.

Oren, W., and Ruland, R., 1985, Survey Computation Problems Associated With Multi-Planar Electron-Positron Colliders, *Proc. of the 45th ASP-ACSM Convention*, pp. 338-347, Washington, D.C.

Pietryka, M., Friedsam, H., Oren, W., Pitthan, R., and Ruland, R., 1985, The Alignment of Stanford's New Electron-Positron Collider, *Proc. of the 45th ASP-ACSM Convention*, pp. 321-329, Washington, D.C.

Ruland, R. and Friedsam, H., June 1986, GEONET—A Realization of an Automated Data Flow for Data Collecting, Processing, Storing and Retrieving, Invited paper presented at the XVIII FIG Congress, Toronto.

SLC Design Handbook, 1984, Stanford Linear Accelerator Center, Stanford University.