

## **SURVEY FOR THE CAMBRIDGE ELECTRON ACCELERATOR**

BY DAVID D. JACOBUS\*

(Presented at a joint meeting of the Boston Society of Civil Engineers and Surveying and Mapping Section, BSCE, held on May 17, 1961.)

THE hydrogen atom may be described as a single proton with a single electron in orbit around the proton. In the isotope of hydrogen, deuterium, the core consists of one proton and one neutron. The elements from hydrogen with an atomic weight of one to uranium with an atomic weight of 238 are progressively complex combinations of protons, neutrons, and electrons.

The Cambridge Electron Accelerator can be likened to a super-microscope that is designed to study the sub-atomic properties of the elementary particles—protons, neutrons, and electrons. The accelerator will produce a beam of electrons of very high energy, something of the order of six billion electron volts, and this electron beam will be used to bombard a target. Energies of this order of magnitude are not needed to break up atoms. They are needed to disintegrate the more elementary particles. A preferred target is liquid hydrogen, which is a relatively pure mass of protons. One of many billions of the high energy electrons may strike the core of a proton and disintegrate the proton into fragments. The number, the weight, the energy and the life span of the fragments can be observed with a view toward learning more about the nature of that very fundamental particle, the proton.

Electrons are injected into the annulus of the Cambridge Electron Accelerator at an energy of 20 million electron volts. A linear accelerator performs this function. The annulus of the accelerator consists of 48 magnetic lenses, each precisely located on a circle of 236 foot diameter. Acceleration of the electrons from an energy of 20 million electron volts to a final energy of 6 billion electron volts occurs in about 8 milliseconds. In this time interval the electrons will have traversed the annulus of the machine about 10,000 times, and will have traveled a distance of about 1,500 miles. The electrons

---

\* Chief Mechanical Engineer, Cambridge Electron Accelerator and Research Fellow in Physics, Harvard University.

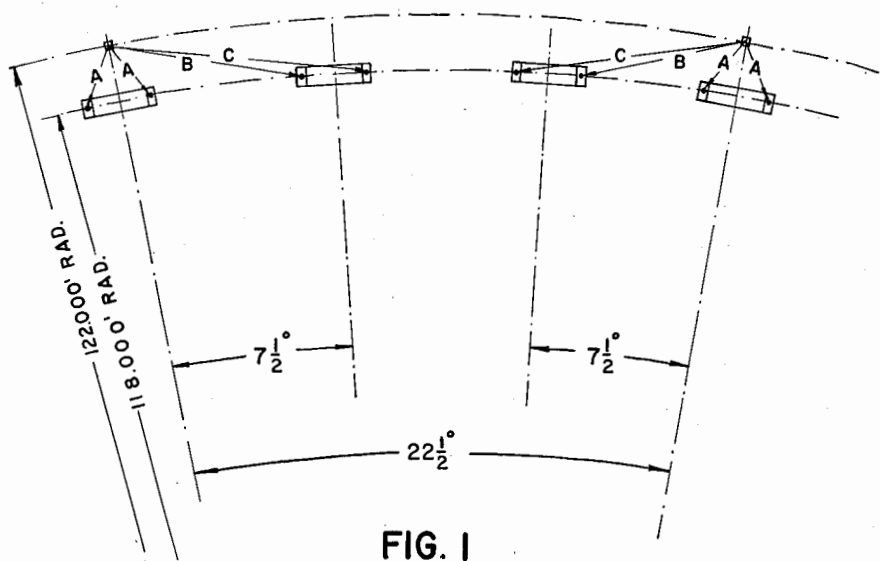
enter the orbit and leave the orbit at essentially the speed of light. At the final energy of 6 Bev, the mass of the electron has been increased almost 12,000 times.

Each of the magnetic lenses consists of a laminated steel core with electrically excited coils around the pole tips of the magnet. The contour of the steel at the magnet pole tip determines the shape of the magnetic field. Each magnetic lens must hold the electrons in the orbit, and must also focus the beam to keep the electrons away from the walls of a surrounding vacuum chamber. The accelerator employs two types of magnetic lenses, one lens focusing the beam in the horizontal plane and the following lens focusing the beam in the vertical plane. The contours of the pole tips were determined by an extensive program of modeling and measuring, and carbide dies were manufactured to produce stamped laminates that do not deviate by more than  $\pm .002$  inches from the calculated values. Girders were machined flat to  $\pm .002$  inches, and guide rails were located radially to the same order of accuracy to align the magnet core blocks on the girders. A twelve foot long girder with superimposed core blocks and exciting coils comprises a magnetic lens. Forty-eight such magnetic lenses, twenty-four vertically focusing and twenty-four horizontally focusing, have been surveyed into place to better than the following of accuracies.

- $\pm .005$  inches in the vertical coordinates
- $\pm .020$  inches in the radial coordinates
- $\pm .060$  inches in the azimuthal coordinates

A girder deflects .008 inches when loaded with the magnet core blocks. Forty-eight symmetrical deflections of this order of magnitude do not distort the electron beam. The girders can be leveled with precision jacks to accuracies of the order of  $\pm .001$  inches. The jacks in turn are supported on steel plates which can be moved radially and azimuthally after all of the equipment is in place. Each of the jack supports, which normally rests on a contacting flat surface, can be carried on ball bearings by applying hydraulic pressure to a cylindrical support. When the end of a girder is carried on the ball bearings, radial and azimuthal adjustments to accuracies of the order of  $\pm .001$  inches can be made by adjusting the positions of peripheral machine screws. After all adjustments are complete, the hydraulic pressure which holds the supporting cylinders against the ball bearings is relieved, and the girders are again supported on contacting flat

surfaces. The entire jack supporting mechanism is coupled to the end of a steel girder with a single  $1\frac{1}{4}$  inch diameter locating pin. A second locating pin is inserted in the underlying base plate. When both pins are in true alignment, the end of a girder is in its correct nominal location, but with the very important consideration that precision adjustments in level, radial, and azimuthal coordinates can be readily made after all equipment is in place.



**FIG. 1**

Ninety-six base plates locate the jack supporting mechanisms. The  $1\frac{1}{4}$  inch diameter holes in the centers of the plates were precisely surveyed into position on a circle of 118,000 foot radius, to form the pattern shown in Figure 1. When the foundations of the building were in process of construction, ninety-six 12 inch building piles were driven 30 feet into the subsoil on a circle of 118 foot radius. A concrete cap was subsequently cast on pairs of adjacent piles. Forty-eight caps support the entire ring of magnet girders. Each cap supports the downstream end of one girder and the upstream end of an adjacent girder. The girder supports have no contact with the floor or with other building components. Magnet girder supports have now been in place for a period of four years. Severe floor settlement

has taken place, particularly in areas adjacent to new building construction, but the magnet supports appear to be relatively stable.

Sixteen survey monuments are equally spaced on a 122.000 foot radius. Four of these monuments can be viewed through radial tunnels from a monument at the center of the accelerator. The supporting pile caps are within  $\pm \frac{1}{2}$  inch of their nominal locations. There exists a location of the central monument which will put the jack supports on top of the supporting pile caps. A suitable location for the central monument was determined by making a preliminary survey, and the central monument was then welded in place. The central monument and the sixteen peripheral monuments are  $\frac{3}{4}$  inch thick stainless steel plates, each with a  $3\frac{1}{2}$  inch diameter tapered hole that will accept a spherical surveying target.

The four monuments at the ends of the tunnels were surveyed into place with the transit at the center of the accelerator. The monuments were held in place with bolted clamps, and were welded to an underlying steel plate when a location was finally established. With the four radial monuments in place, the remaining twelve monuments were equally spaced on a circle of 122 foot radius. A survey made after all plates were welded in place showed that the following accuracies had been achieved.

#### *Monuments at Radial Tunnels*

Maximum recorded angular error	= 3 seconds of arc
Maximum recorded error in radial length	= .0003 feet

#### *Sixteen Monuments in Tunnel*

Maximum recorded error in angular alignment	= 40 seconds of arc
Maximum recorded error in linear displacement	= .0025 feet

Note that the measured lengths are relatively more accurate than the measured angles.

The sixteen peripheral survey monuments were used in conjunction with three spacer bars, "A", "B", and "C", to locate all 96 jack supporting plates, as indicated in Figure 1. Each spacer bar terminated in a spherical insert that fitted into the tapered hole of a survey monument. The other end of the bar contained a pin for holding the base plate, with superimposed optical target that could be sighted with a transit to locate the bar in the desired angular position. When a jack supporting plate was aligned with spacer bar and transit, it

was immediately tack welded in position to the underlying steel plate. After all 96 jack supporting plates were welded in place, a final survey of the locating holes was made. This showed that all holes lay within  $\pm 1/16$  inch of the 118.000 foot radius, and that the linear distance between adjacent holes in no case deviated by a larger amount from the true nominal value. This final overall accuracy, after a total of as many as seven successive operations, was achieved by making each individual measurement to a precision limited only by the performance of the instruments.

Invar tapes, inscribed at one end with graduations at each .005 foot interval, calibrated to overall accuracies of  $\pm .0003$  feet and to relative accuracies in a one foot interval of  $\pm .00005$  feet, were furnished by Keuffel & Esser Company. The tapes were observed with a Bausch & Lomb shop microscope with special illuminated scale graduated at each .0001 foot interval. Farrand optical targets were used to show the centerline locations of the tapered holes in the surveying monuments. A Wild T2 theodolite was used to make all angular measurements.

With the jack supports and the magnet girders in place, the sixteen peripheral survey monuments have served their function and may never again be used. The tops of all magnet core blocks have subsequently been brought to a common level with an accuracy of about  $\pm .002$  inches. Fixtures have been devised to secure direct measurements of the relative radial locations of the magnet core blocks. The positions of the core blocks have been adjusted to bring the radial coordinates within the desired  $\pm .005$  inches of nominal. Leveling and adjusting the magnet core blocks to suit the needs of the accelerator is an extensive program that is still in progress under the direction of Dr. William Shurcliff.

The author gratefully acknowledges the skill and care exercised by Harry R. Feldman and Company, who performed the survey that is described in this paper.