Current Alignment Topics at CEBAF*

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Introduction

The Continuous Electron Beam Accelerator Facility (CEBAF) will be a high intensity, continuous wave electron accelerator for nuclear physics when completed July of 1993. It will provide a continuous beam at energies between 0.4 and 4.0 GeV to one or more of three experimental halls. To serve more than one experiment at a time, the intensity of the electron beam will be **200μA** with a duty factor of 100%.[1]

These goals will be achieved by building a recirculating accelerator utilizing two 0.4 GeV superconducting linacs connected by transporting arc magnets. Figure 1 shows an overall schematic of the machine, which highlights the fanned recirculation arcs. The path for a typical electron would start at the 50 MeV injector and continue to its injection into the first 0.4 GeV linac. After acceleration, the electron is bent off to its appropriate recirculation arc (in this case the top beamline of five) to be transported to its reinjection into the second linac. Here it again is accelerated and bent through an arc to be reinjected into the first linac. This process can continue for five cycles until the beam is at 4.0 GeV, or it can be extracted at the end of the second linac to provide beam energies of 0.4 GeV and upward.

The centerpieces of this machine are the superconducting continuous wave linacs. These are made up of twenty 8.25 meter long cryomodules, each containing eight superconducting accelerating cavities. These niobium structures are immersed in a bath of liquid helium at 2K and isolated from the outside world by a multilayered superinsolating cover. The spaces between the modules, called the warm regions, contain a quadrupole, a beam position monitor and steering correctors. These are supported on a common girder (Figure 2) with its own adjustment system with dial gauge feedback.

The recirculating arcs are composed of a series of dipoles and quadrupoles to bend and focus the beam around a 180 degree bend for reinjection into the next linac. Since this is a five pass machine with different energies for each pass, separate beam lines are needed for each recirculation. This has necessitated the stacking of components on common support systems to fit in the 4 meter wide and 3 meter tall tunnel. (Figure 3)

The total beam path for a full five pass accelerating cycle is over 6 km. This leads to a total element count of over 2300. Table 1 details the magnet types and their

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individual totals. One should note the large numbers of differing magnets each with its unique fiducialization requirements.

Alignment Tolerances

Table 2 outlines the general alignment tolerances for the machine. The total budget includes fiducialization errors as well as placement errors associated with surveying. The tolerances also assume that a local smoothing routine will be applied to the beam line. This will localize the tightest tolerances for quadrupole alignment to an area of ±25 meters from the element in question. The DIMAD simulation indicates that the accelerator will remain robust at up to twice these tolerances which provides for short and midterm settlement errors.

Survey and Alignment

General Philosophy

The beam line alignment will be a multi-stepped process combining optical tooling and theodolite based survey systems. The first step will be the placement and prealignment of the support systems. This will be followed by an alignment of installed components before vacuum and utility hookup. Up to this point both optical tooling or theodolite surveys will be employed. A final survey step utilizing redundant theodolite and distance observations of the relative positions of adjacent components will then be made. The data will be smoothed to obtain dial gauge motions to be applied to each element. A final check survey then follows.

Hardware and Software

Currently the equipment inventory includes split bubble geodetic levels with their associated 0.5 cm invar rods, electronic theodolites, optical plummets and the ME5000 distance meter for measuring distances of 7 meters and above. A complete array of optical tooling equipment is also available. Future purchases of laser trackers to speed the alignment of components are anticipated. To prepare for this eventuality, a monumentation system has been developed to accommodate 1.5 inch spheres containing retro-reflectors. Figure 4 shows a typical floor monument cup which can mount either a retro-reflector, a target sphere for centering over, or a solid sphere for a leveling reference. What has resulted is a three-dimensional monumentation system which can work for traditional horizontal and vertical surveys as well as three dimensional coordinate measuring systems.

The SLAC developed Geonet data handling system has been adopted as the basis for building a CEBAF software system. This will include cooperation with SLAC to form a generalized smoothing routine for irregularly spaced beam line components. Included is the generation of an ideal coordinate calculation system utilizing fiducialization and beam simulation data bases.

Control Networks

The general philosophy of a primary and secondary hierarchy of control networks will be used at CEBAF. The difference from previous accelerators is that the primary network will not be based on a surface survey transferred to the tunnel. Rather, a sparse high precision skelton network utilizing the strengths of the ME5000 will be measured in the tunnel. Figure 5 shows a simulation of such a network with maximum error ellipse dimensions of less than 1 mm. This is well within the machine's absolute size requirements.

These primary control points will be fixed and used as the basis of a denser secondary network for beam alignment. The points will be placed to minimize the number of observations necessary for the smoothing routines while also providing monuments close to the beam line for optical tooling setups. The crowding of beam components and the blocked lines of sight which accompany them indicate that the secondary network could be extremely dense. One method of eliminating some of the network points would be to include laser tracker measured distances and directions from conveniently located setups whose positions are resected from known control points. The rapid development of these systems make this an attractive alternative for the near future.

Fiducialization

Most magnets have surfaces machined into their bodies for the registration of survey reference fixture. Figure 6 shows a first concept for a quadrupole clamp carrying two reference fiducials. This fixture clamps to grooves whose locations relative to the magnetic centerline of the magnet have been measured. The assembly carries two cups which will hold the 1.5 inch spheres developed for the control monumentation. This provides for future laser tracker measurements. A similar system to position the regular arc dipoles will be utilized.

The remaining dipoles in the congested areas of the beam line will have tooling ball sockets machined to known locations relative to the poletips. Cryomodules will also use tooling balls as references. Their locations will be measured relative to the internal alignment coordinate system defined during construction. A theodolite based coordinate measuring system provides a method for making the transfer.

References

1. CEBAF Design Report, Continuous Electron Beam Accelerator Facility, May, 1986.

Table 1
Element Counts

Magnets:	
Quadrupoles (7 types)	**698**
Bending Dipoles (27 types)	**386**
Sextupoles	**96**
Septa	**26**
Corrector Dipoles	**1021**
Total:	**2227**
Cryomodules	**42 1/4 (338 Cavities)**

Table 2
Total Alignment Tolerances

Element	Parameter	Tolerance
Quadrupoles	σ_x or σ_y	0.2 mm
	σ_z	5.0 mm
	σ_{roll}	1.0 mrad
Dipoles	σ_x or σ_y	0.5 mm
	σ_z	5.0 mm
	σ_{roll}	1.0 mrad
Cryomodule Assembly	σ_x or σ_y	1.0 mm
	σ_z	5.0 mm
	σ_{yaw} or σ_{pitch}	4.0 mrad
Path Length	σ_L	5.0 mm

- **Assumes Gausian distribution truncated at $\pm 2\sigma$**
- **Machine stays robust at twice the above tolerances to provide for medium term settlement.**

MACHINE CONFIGURATION CEBAF

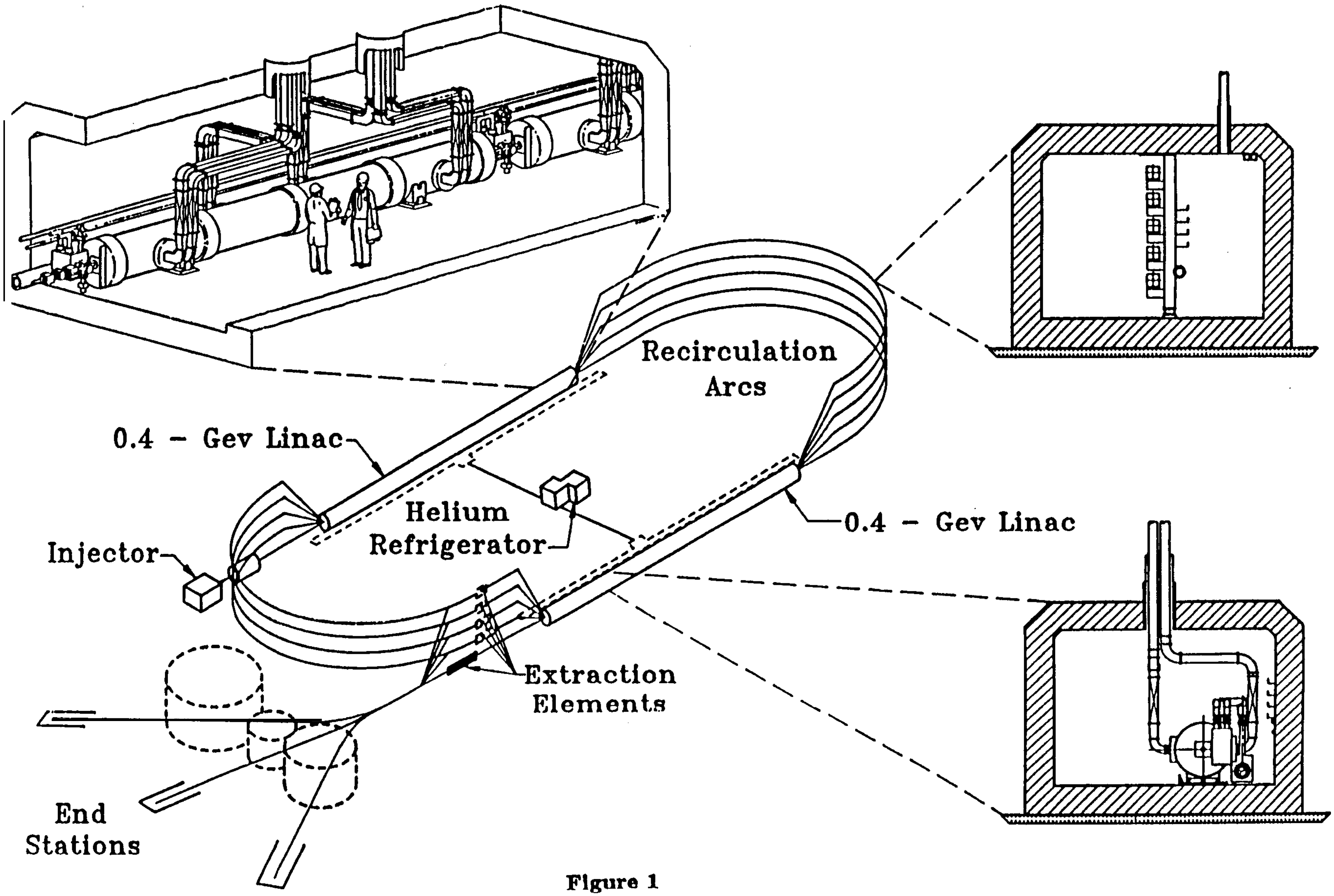

Figure 1

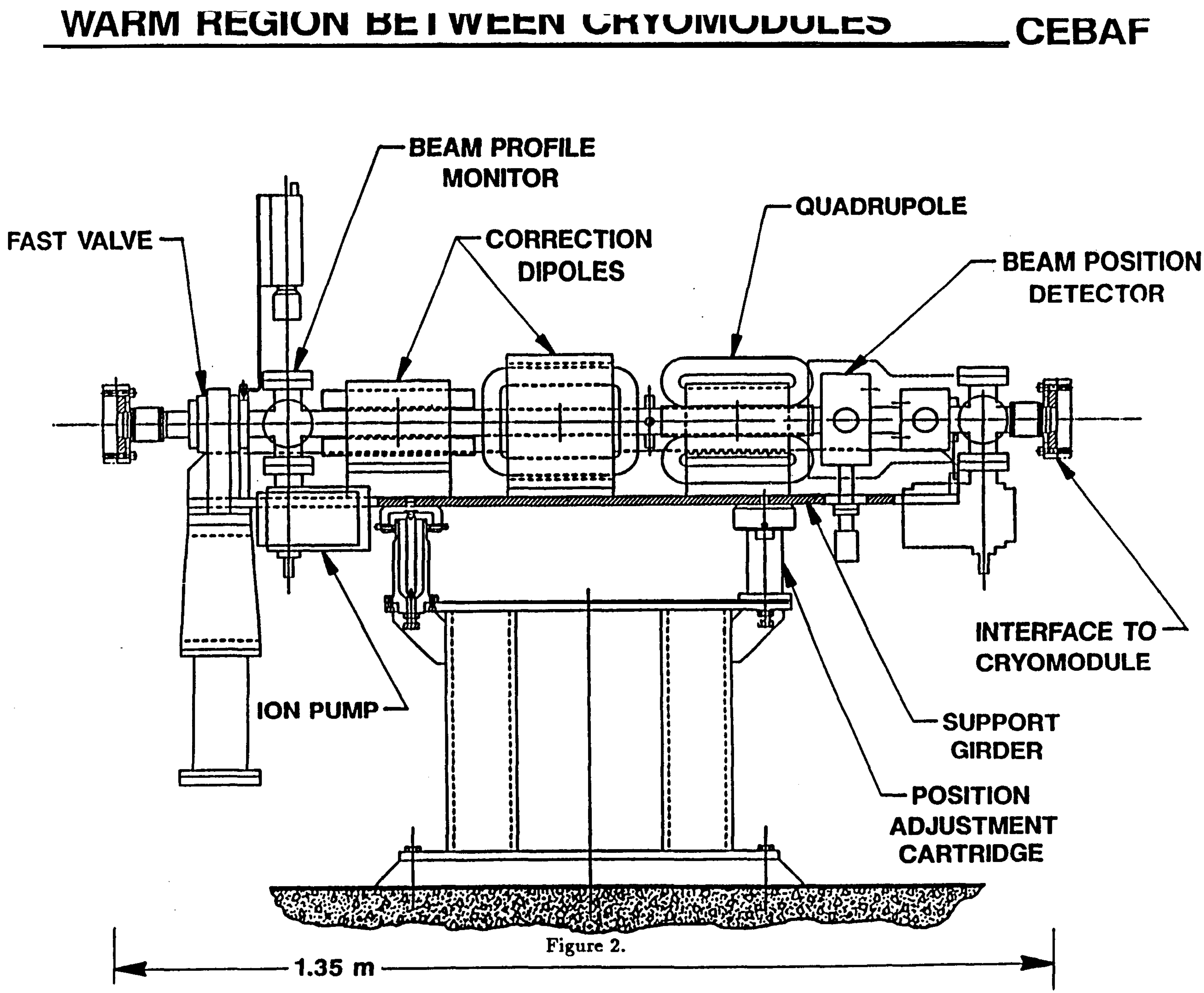
WARM REGION BETWEEN CRYOMODULES
CEBAF
FAST VALVE
BEAM PROFILE MONITOR
CORRECTION DIPOLES
QUADRUPOLE
BEAM POSITION DETECTOR
ION PUMP
INTERFACE TO CRYOMODULE
SUPPORT GIRDER
POSITION ADJUSTMENT CARTRIDGE
1.35 m

Figure 2.

TYPICAL ARC CROSS SECTION
SHOWING STACKED QUADRUPOLES

CEBAF

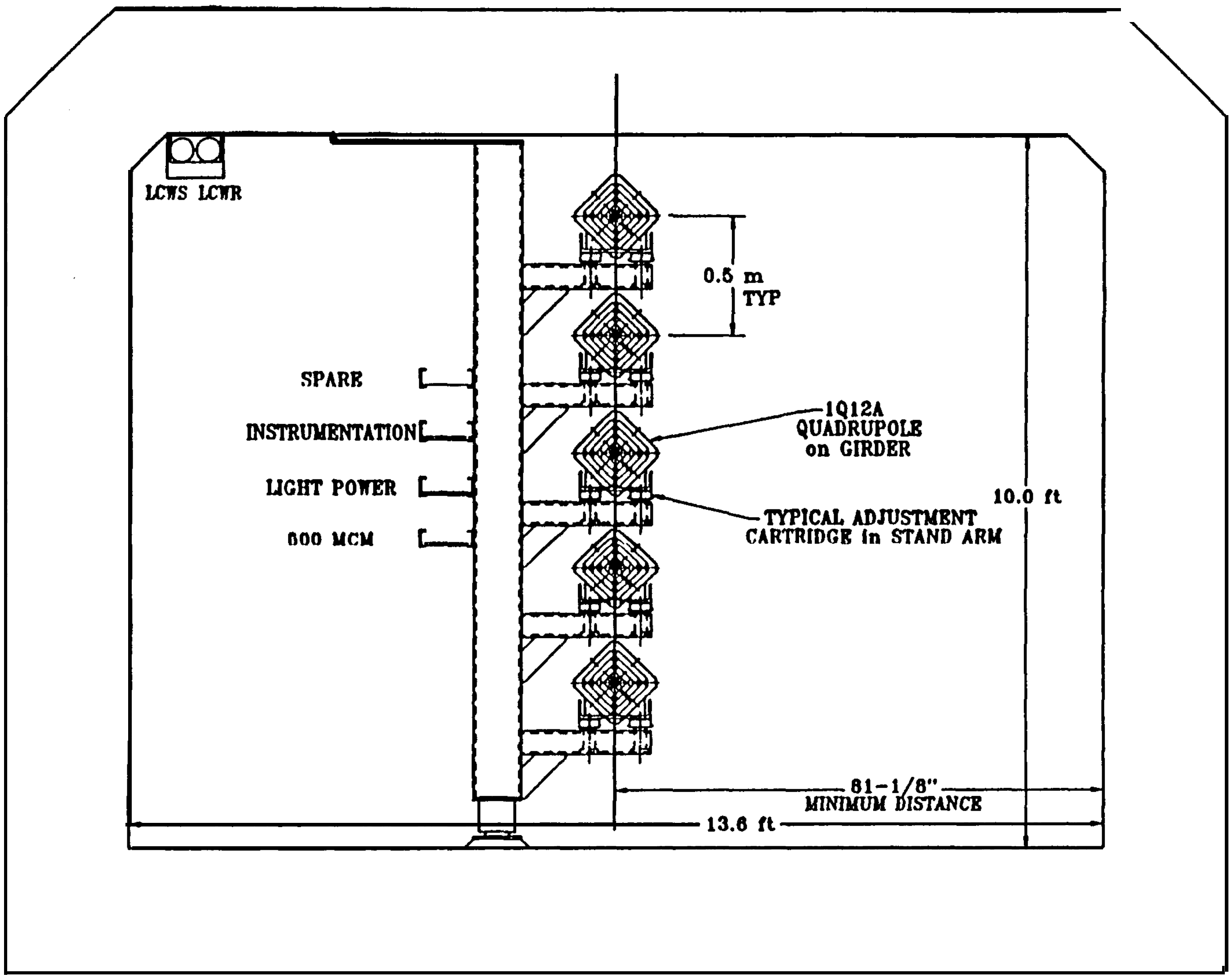

Figure 3.

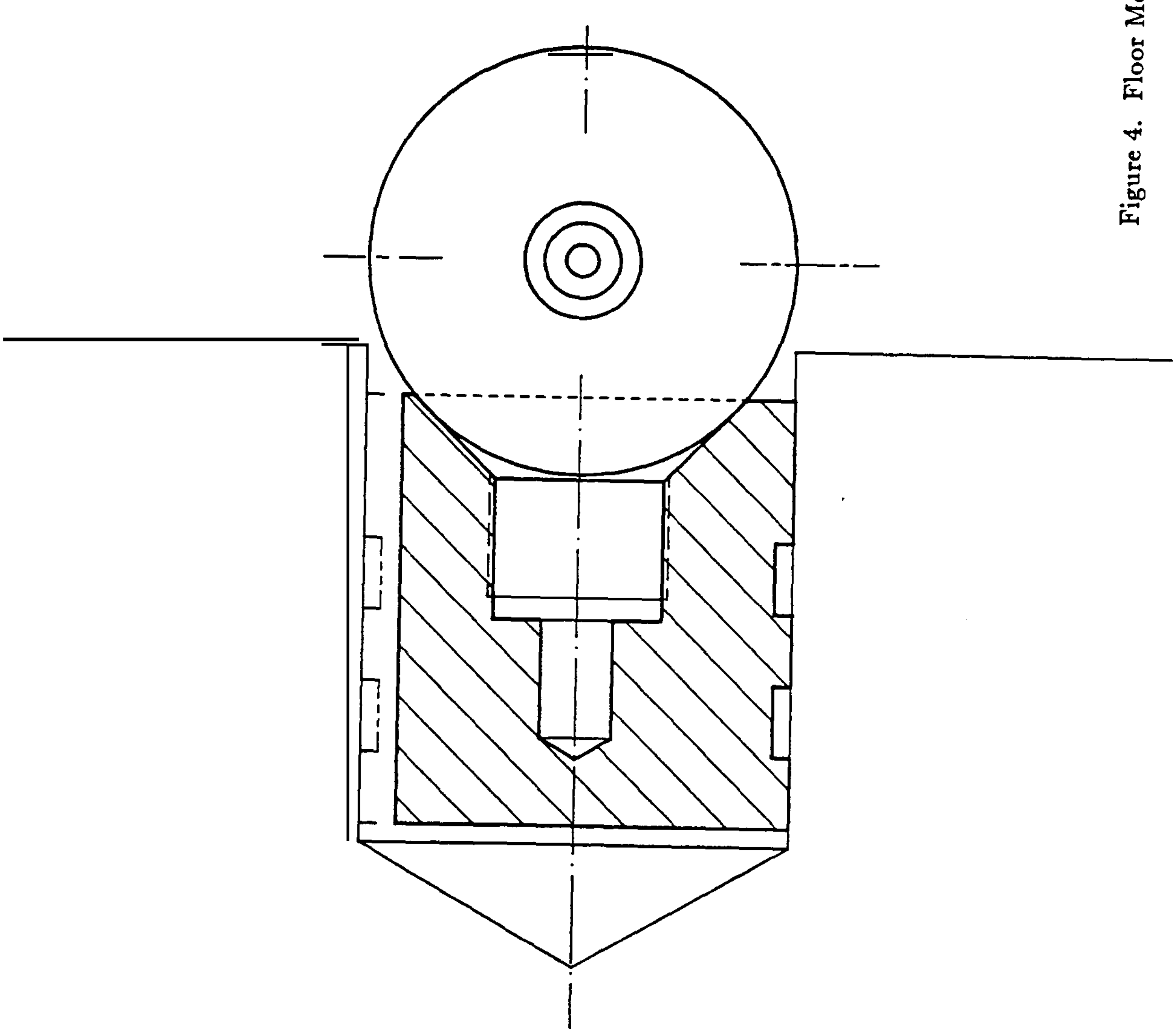

Figure 4. Floor Monumentation.

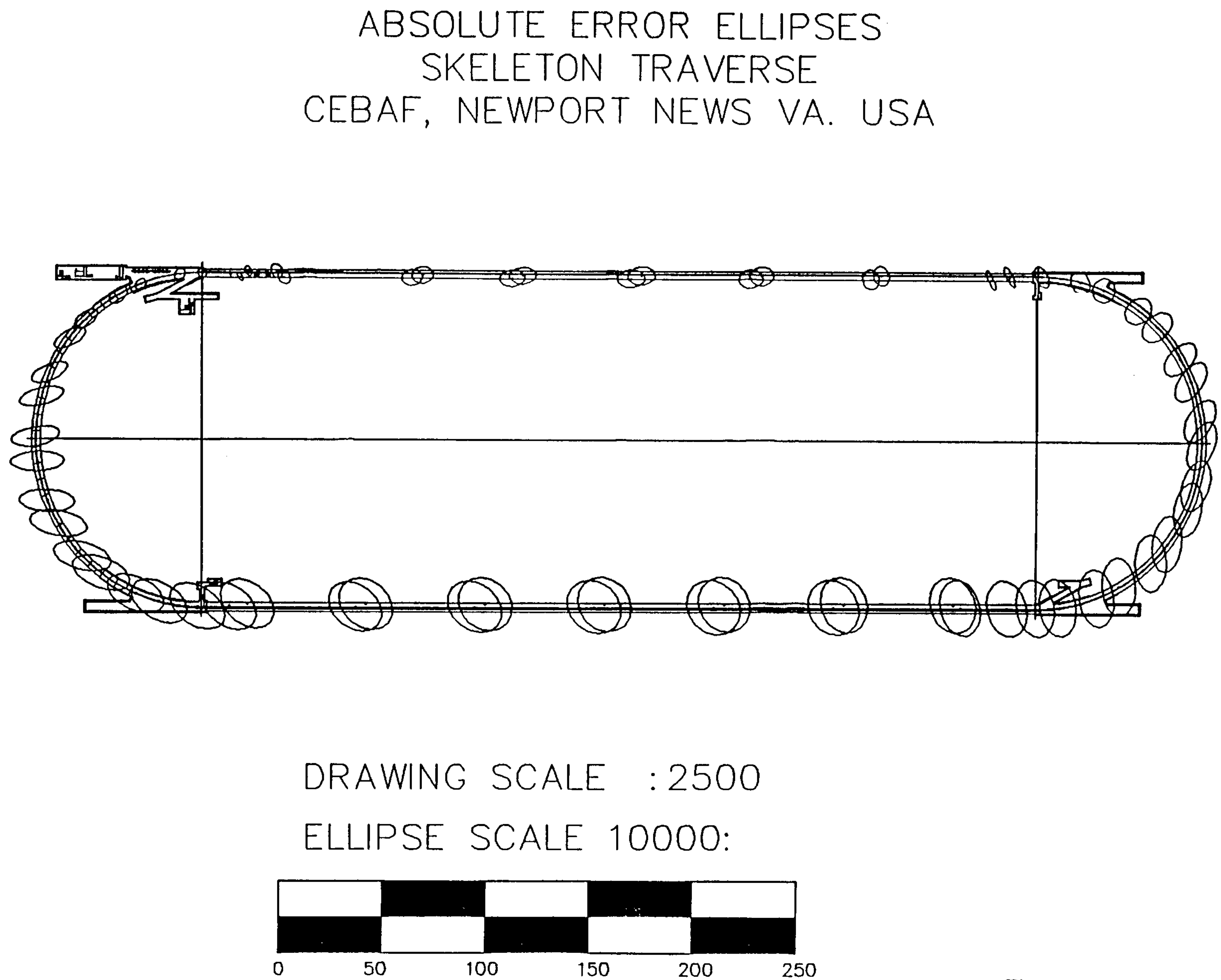
ABSOLUTE ERROR ELLIPSES
SKELETON TRAVERSE
CEBAF, NEWPORT NEWS VA. USA
DRAWING SCALE :2500
ELLIPSE SCALE 10000:
0
50
100
150
200
250

Figure 5.

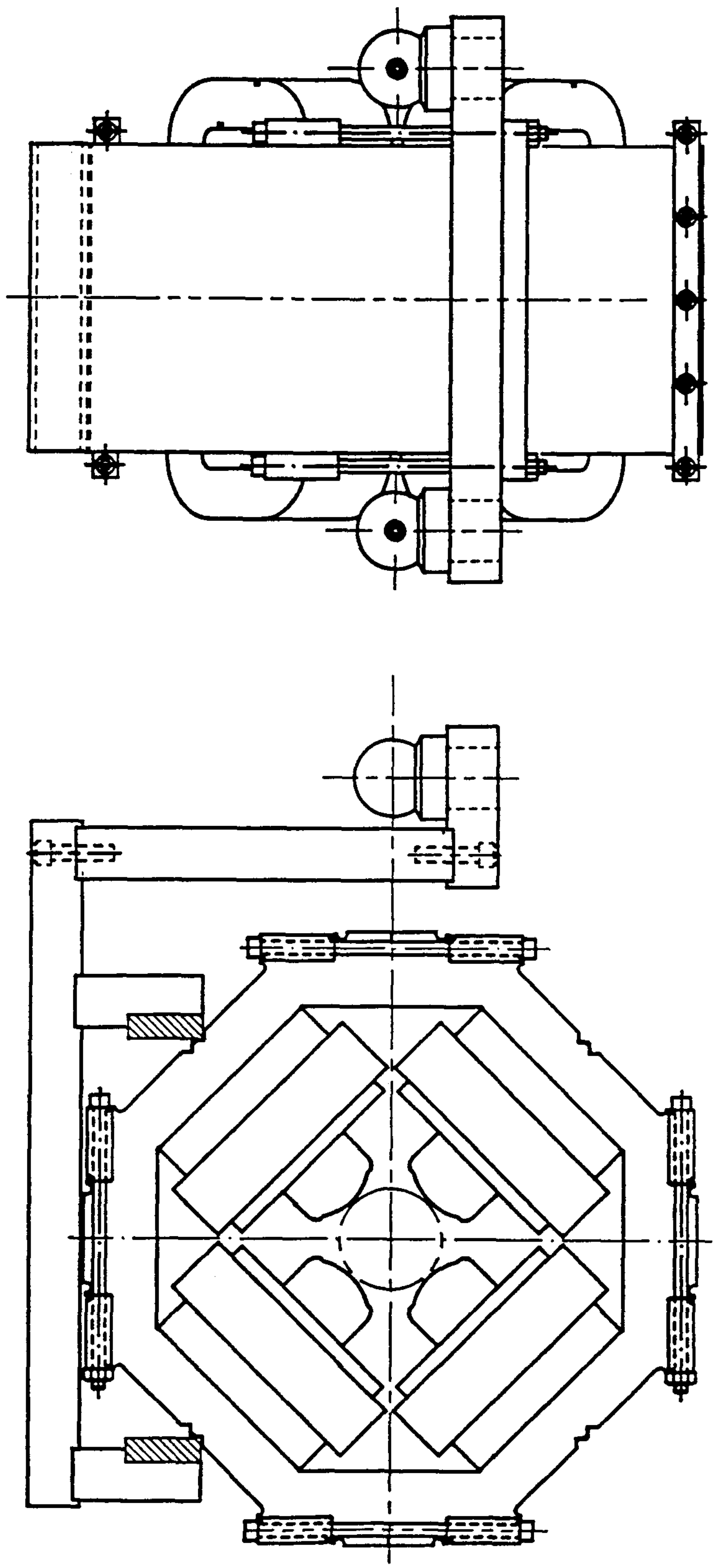

Figure 6. Quadrupole Alignment Fixture.