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FINAL FOCUS TEST BEAM ALIGNMENT - A DRAFT PROPOSAL -

G.E.Fischer, R.E.Ruland

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94309

1. Introduction

1.1. GENERAL OUTLINE OF THE FINAL FOCUS TEST BEAM

In its present form, the Final Focus Test Beam (FFTB)[1] is a transport line designed to transmit 50 GeV electron beams of SLC emittance (3×10^{-10} radian-meters) straight through the central arm of the Beam Switchyard (BSY C line) with a final focus point out in the Research Yard but relatively near the end of the switchyard tunnel. The axis of the incident beam coincides with that of the SLAC linear accelerator; the final focus, some 300 meters downstream, is displaced from this axis by about 2 meters horizontally.

1.2. ORIGIN OF GENERAL ALIGNMENT SPECIFICATIONS

Several optical designs for this transport system have been developed and studied by Oide[2]. So that the promise of extraordinarily small final focus spots ($\sigma_x \approx$ 3 micrometers,$\sigma_y \approx$ 60 nanometers) may be realized, focusing elements, (quadrupoles and sextupoles), should be placed on the design trajectory to absolute accuracies of order fractional to several microns in transverse position. These values, calculated for each element as if it alone were out of place, derive from the fact that off axis trajectories are subject the variations of phase advance and dispersion thereby causing growth of the spot's area at the final focus by a factor of $\sqrt{2}$. For reasons that will become more evident later, we will call these values *the incoherent "jitter" tolerances.*

⋆ Work supported by the Department of Energy, contract DE–AC03–76SF00515.

J.J.Murray has taken one of the Oide proposed cases (FFTF34)[3] and analysed the effects of permitting much larger (perhaps surveyable) imperfections in the position and strength of magnets and Beam Position Monitors and finds that the system is "correctable" without a "significant" (more than say $\approx 30\%$) loss of performance (effective luminosity). Other cases (for example FFTB59) are currently under consideration and appear to exhibit similar sensitivity to imperfection. The magnitudes of these errors, randomly applied to all elements in the system by Murray in a binary way, are shown in Table 1. We will use these values as a guide in the following discussion. Clearly, the better (ie. smaller) such "standard tolerances" achievable, the higher will be the probability of achieving the goals of this project. For the moment we will define the range 5 to 10 micrometers in transverse displacement error as the "specification" for this alignment proposal. In this sense, the values calculated by Oide, which we have called jitter[4] are "operational tolerances" which, if exceeded, call for an orbit correcting and retuning of the beam.

1.3. SCOPE OF THIS PROPOSAL

The hardware, methods and procedures outlined in this proposal are dedicated to measuring the placement of mechanical objects with respect to certain defined geometric axes. We wish to emphasize that the very difficult problems of locating (a) the effective magnetic axes of focusing elements, (b) the effective electrical center of beam position monitors and (c) even the effective axis of the incident beam relative to mechanical reference surfaces is outside the scope of this work. Further, this proposal is restricted to the act of measurement and does not consider the vital task of on-line mechanical repositioning of elements that will, in likelihood, be called upon during operation of the system.

2. Concept

2.1. OUTLINE OF METHOD

The narrow forward geometry of the FFTB lends itself to the method of "survey by offsets". The main task is, therefore, the establishment of an absolutely straight line whose axis can be related to that of the linear accelerator, the agency which provides, presumably with little or no steering, the beam's input direction to the system.

Fortunately, the original planners of the SLAC BSY provided just such a straight line[5] which was used to layout the geometry of the energy defining slits in the A and B lines, as well as providing a C line reference. As will be shown later, with some reconfiguration and additions, the BSY laser alignment system should have adequate resolution and accuracy to serve as the primary reference line, independent of tunnel monuments that may shift with time or the effects of atmospheric refraction. Moreover, this laser based system can be used while the beam is in operation, thereby providing the means for on-line check on the straightness of the reference line and hence indirectly on the coordinates of components.

The steepest angle the beam trajectory makes with respect to the reference line is of order 20 milliradians. This means that offset measurements between the trajectory and the reference line must be made at "s" and "z" distances known to better than 0.1 millimeters if the error introduced in transverse measurements is to be kept less than 2 microns. For the long simple longitudinal distances of this problem, 0.1 mm accuracy can be reached using an "electronic distance meter" (Kern Mekometer ME5000) or with certain restrictions the interferometer calibrated "distinvar wire".[6]

Figure 1 depicts a crossection of the BSY C line tunnel taken at a point sufficiently downstream so that the FFTB trajectory has diverged from the laser reference line. We will discuss in following sections the details of the components and their expected performance.

2.2. PLACEMENT RESOLUTION OF A BSY LASER ALIGNMENT FRESNEL LENS.

The concept of the SLAC laser alignment system is depicted in Figures 2 and 3. The idea is disarmingly simple. If all lens centers lie along a perfectly straight line, all will focus the divergent light from the source to the same spot in the far focal plane. If some lens is off axis by an amount $\Delta x, y$, (See Fig.4) the focal spot is displaced by an amount

$$\Delta x', y' = \frac{(r+s)}{r} \times \Delta x, y \tag{1}$$

in which "r" is the distance from the source to the lens and "s" is the distance from the lens to the focal plane. Referring to Equation 43 of the Herrmannsfeldt et al. article[7] the diffraction limited full width at half maximum w of the central image is given as:

$$w = \sqrt{5}/\pi \left(\frac{\lambda s}{D} \right) \tag{2}$$

in which λ is the wavelength of the light (normally red light of wavelength 632.8 nanometers), and D is the effective diameter of the lens.

If we were to use the configuration of the *existing* BSY system, (shown schematically in Figure 5) we note that the source is near the far eastern end of the BSY tunnel but the focal plane is at far western end of the accelerator located over two miles away. This arrangement has the advantages of sharing a common detector with the accelerator laser alignment system and high sensitivities due to large lever arms l/r. But this configuration may also have the disadvantage, as will be shown below, of rather large image sizes since s is the length of the accelerator.

Inserting values for the BSY lens closest to the BSY source, we have $r = 46.5' + 7.6' = 54.1'$, $s = 10,936.5' - 54.1' = 10,882.4'$, $D = 5.5"/12" = 0.46'$, hence the calculated w is a perhaps uncomfortable 10.6 mm. Experimentally, in fact, this image is far larger; perhaps four times as big as it should be. It was speculated that for close lenses, the assumption of a "point" source was violated.

Assuming for the moment that the detector is able to locate the center of the image to 1/100 th of its size[*], and applying the lever arm of Equation (1), the resolution to which the position of the lens can be located is: $27mm \times 1/100 \times 54/10936 = .0021mm$ or 2.1 micrometers. Laser targets at the upstream end of the BSY, where they overlap the accelerator system by the means of "double targets" have less lever arm but substantially the calculated size. The resolution there should be about $10.6mm \times 1/100 \times 952/10936 = .0092\text{mm}$ or 9.2 microns. Of course it should be realized that in order to use the presently existing BSY equipment for the new transport line, the existing lens holders and the laser station will need to be relocated. The foregoing were sample calculations to show that resolutions consistent with requirements should be achievable.

2.3. REPEATABILITY OF BSY LASER TARGET INSERTION

The efficacy of the method depends on the ability of inserting BSY type lenses, one by one, with repeatabilities of position to better than the suggested resolution. Since it has been known for some time that some of the 297 hinge mechanisms of the large accelerator lenses suffer from a lack of repeatabilty at the 25 micron level, a test was performed on a spare BSY lens actuator.(Assembly drawing AD-904-522-00 R4 dated 7/28/66) Figure 6 is a photograph of the actuator installed in the BSY laser vacuum pipe. This device was mounted within the working aperture of a large, three axis, coordinate measuring machine and exercised by hand. The results of nine insertions are shown in Figures 7 and 8. The repeatability in the vertical direction (radial with respect to the shaft roller bearing) is excellent, showing a full width of about 1.5 microns. The horizontal spread (in line with the axis of the hinge shaft) is about 7.5 microns but can most probably be improved by a addition

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[*] This value depends in detail on the type of detector employed and will be discussed in Section 3.5

of a spring. These tests do not prove that the other 20 or so units installed in the BSY over 20 years ago will perform entirely satisfactorily, (tests have not yet been performed), but lead one to the notion that they too can be used.

2.4. COORDINATE TRANSFER FROM CENTER OF FRESNEL LENS TO NEW TOOLING OUTSIDE THE VACUUM ENCLOSURE

Having established that lenses can be inserted into the laser line of sight in a repeatable way, the coordinates of the lens axes must be transferred to reference tooling located outside the vacuum enclosure. The original tooling, a K & E mirrored target for x and z, and a tooling ball for the y coordinates were meant to be used in connection with the "standard optical alignment" methods employed 20 years ago. These methods were particularly applicable because technicians were to observe these targets with telescopic instruments mounted on the upper gallery of the BSY, (see Figure 9) well removed and shielded from beam elements such as collimators, that might become intensely radioactive. These methods, will not suffice for micron accuracies. Moreover, it will be important to monitor positions while the beam is in operation. Figure 1 shows a possible "offset arm" between a beam element and the laser target housing. Because the precise method of readout has not been chosen, it is too early to specify the tooling that will be required. What we can say is that today extraordinarily precise three dimensional coordinate machines exist in this immediate area that can measure relative mechanical distances with micron accuracies. It should be added that these same devices equipped with optical probes can be used to examine the fresnel lenses for asymmetric errors of construction that would lead to systematic errors in the positions of their laser light images.

2.5. COORDINATE TRANSFER FROM THE LASER TOOLING STATION TO A COMPONENT TOOLING STATION

It is the function of the already mentioned "offset arm" to relate the coordinates of the tooling on a quadrupole, for example, to that on a laser station. We have not decided exactly what form of measurement will prove to be the most appropriate. The suggestions listed below should be followed up experimentally and developed into reliable and cost effective solutions.

Horizontal What ever reading mechanism is proposed, it seems useful to provide a mechanical, albeit floating, bridge to support the instrumentation across the, up to two meter, span.

1.Interferometry

Perhaps the most accurate absolute measurement of distance between the tooling on the component and that on the reference housing is by means of standard metrological interferometry. Over a flight path of two meters, the distance uncertainty should remain below about 1 micron in spite of the combined errors due to temperature, pressure and humidity of the intervening air as well as the uncertainty in the instruments' stabilized wavelength and its ability to resolve fringes.[8] It must be pointed out however that this technique is relatively expensive and not too well suited to being employed in the field. This is particularly true if used in multiple widely separated areas or for remote reading during beam operation. We believe, however, that the tooling and the "arm bridge" should be designed so that initial standardization and recalibration of other instrument types be possible by this method.

2.Invar rod method

It is entirely possible to suppose that the arm bridge carry a fixed calibrated invar rod, one end of which is fastened to the tooling on one side, the position of the other end read by sensing elements having micron resolution. Since these elements have to read stably over relatively short distances (say 1 mm to 1cm), a wide variety of radiation resistant instrument heads come to mind. Among these are the SONY Magnascale and high precision LVDTs, magnetic or capacitance proximity gauges.

3.Plain rod method

The expense of Invar rods can be traded against the necessity of measuring the average temperature of an ordinary metal transfer rod. What is gained in capital cost is lost in computer read instrumentation channel cost and extra laboratory calibration. This tradeoff has not yet been evaluated.

Vertical We propose to transfer vertical coordinates by means of hydrostatic levels whose liquid containing tubes are carried by the bridge and whose wells are fixed to the tooling at each end. By keeping the riser heights below, say one centimeter, temperature effects will not need to be compensated for. We have not yet chosen the fluid or method of height read out. Mercury has been used with excellent results[9]. The difficulties of using water with a high precision capacitance read out appear to have been solved by Roux.[10] (See Figure 10) It would be very useful to develop the short range laser diode driven interferometer[11] in conjunction with the mercury pool suggested by Olsfors[12] for in situ absolute calibration of the radiation resistant readout sensors.

Although we do not need to consider the effects of perturbations of the local gravity vector on the average geoid at SLAC over the short offset distances involved, it should be pointed out that very careful attention most be paid to the coordinate systems of the linac and of the BSY laser systems. They are neither parallel to each other nor normal to the local gravity vector at any point along their length.(For details see Reference 5 and Figure 11). For this reason carefully machined shim blocks are called for to compensate for the resulting height differences of the various components along the beam line.

2.6. ROLL, YAW AND PITCH

So far we have described the precision measurement of the transverse and, to a lesser accuracy, the longitudinal coordinates of components. A solid is, however, defined by six parameters. Assuming for the moment we can mount the coordinate tooling to reference the nodal point of a component, (the effective electrical center) studies have shown that we do not need to measure the three angles with extreme accuracy. (Milliradians are sufficient) For this reason we presume that they can be measured by more conventional means (transits, kevlar strings and the like). There is, however, one angle that may require more care; the roll angle (θ_z) of bending magnets. Fortunately there exist today remote reading tiltmeters of sufficient accuracy, near zero angle, to solve this problem.

3. Recent Experiences with the BSY Laser Alignment System

The BSY system has been in disuse since the onset of the SLC construction program in summer 1984. At that time high-power slits were removed to make room for the Arc transport system. Although target stations 5 through 9 are therefore no longer in service, the pulse magnet group and laser vacuum system was reassembled. To the best of our knowledge it was not used till February of this year when a new laser was installed.

We are pleased to be able to report the following observations:

1. The Fresnel targets of all but one of the remaining 17 target stations could be inserted on demand.
2. With the exception of the last target (No.20), the widths of the images observed over 10,000 ft downstream, were consistent with those calculated in Table I. This table is an updated version of one listed by Herrmannsfeldt[13].
3. Relative to the double target at the end of the accelerator (Station 30-9), a very cursory look indicates that Stations 12,13,14,15,17,18,19 appear to be on a straight line to within about 0.1 mm. Since it is very unlikely that the

TABLE I. Beam Switchyard Fresnel Lens Calculations

Targets with center slot open - Overall length 10936.5'

STATION	COORD.	DIST. S (FEET)	DIST.R (FEET)	FOCAL L (FEET)	T SIZE (INCHES)	NO.HOLES	IMAGE WID (MM)	RESOLUT. (MICRONS)
DETECTOR	-178.500	0.000	10936.500					
MONUM 30	9984.432	10162.932	773.568	718.851	5.445	36	10.09	7.1
DRIFT 300	9990.610	10169.110	767.390	713.544	5.425	36	10.13	7.1
1	10010.402	10188.902	747.598	696.494	5.361	36	10.27	7.0
2	10049.902	10228.402	708.098	662.251	5.377	38	10.28	6.7
3	10080.423	10258.923	677.577	635.597	5.410	40	10.25	6.3
4	10105.516	10284.016	652.484	613.556	5.452	42	10.20	6.1
5	10110.750	10289.250	647.250	608.944	5.431	42	10.24	6.1
6	10117.875	10296.375	640.125	602.658	5.399	42	10.31	6.0
7	10135.958	10314.458	622.042	586.662	5.459	44	10.21	5.8
8	10139.126	10317.626	618.874	583.853	5.440	44	10.25	5.8
9	10157.209	10335.709	600.791	567.787	5.492	46	10.17	5.6
10	10168.250	10346.750	589.750	557.948	5.450	46	10.26	5.5
11	10204.604	10383.104	553.396	525.394	5.406	48	10.38	5.3
12	10458.779	10637.279	299.221	291.034	5.488	88	10.48	2.9
13	10471.902	10650.402	286.098	278.614	5.492	92	10.48	2.7
14	10511.000	10689.500	247.000	241.422	5.481	104	10.54	2.4
15	10565.000	10743.500	193.000	189.594	5.482	134	10.59	1.9
16	10585.625	10764.125	172.375	169.658	?	?	?	?
17	10615.250	10793.750	142.750	140.887	5.484	180	10.64	1.4
18	10631.250	10809.750	126.750	125.281	5.482	202	10.66	1.2
19	10647.250	10825.750	110.750	109.628	5.498	232	10.64	1.1
20	10704.000	10882.500	54.000	53.733	3.768	240	15.61	0.8
MIRROR	10750.500	10929.000	7.500					
LASER	10758.000	10936.500	0.000					

mountings have been realigned in the last 5 years (perhaps two decades), this observation speaks for the remarkable stability of the downstream part of the Beam Switchyard Tunnel floor and of the original laser target housings. Target 16 is misaligned by about 1mm. We note that it is mounted on an stand made of bolted together dexion angle steel.

4. Figure 12 is a photograph of the image from a BSY Fresnel lens. This picture shows that the far wings of the pattern can be used to determine the relative roll of target stations. A lens insertion mechanism is shown in Figure 13. A contact Xerox image of an actual BSY target is shown in Figure 14.
5. The image plane of the observation station has been equipped with a new form of position readout. The oscillating image differentiating scanner has been replaced by a modern CCD camera shown in Figure 14. In its first form, suitable for image widths below 1 cm, the light falls directly on the array. The image is digitized on a gray scale and may be enhanced by a series of filter-programs resident on a local PC. The computer and its digitized output are shown in Figure 16. Various algorithms have been written to find the "center" of the image. Tests are under way to determine the best methods. For images larger than those easily accommodated, a simple demagnifying lens is called for. It goes without saying that the whole panoply of todays' computer aided image enhancement techniques may be employed[14] to rapidly find centers of images to better than 1/100 th of their width.

During recent exercises with the main accelerator laser alignment system using targets in Linac sectors 1 and 2, early results in a semi-automated data acquisition mode resulted in overall position repeatabilities in the 4 micron range.

4. The Proposal

From the aforesaid discussion one is led to the notion that technology existing at SLAC demonstrably permits the establishment of a *straight line reference system* from which the coordinates of beam-line components may be determined, monitored and maintained. The proposal, therefore, is to extend such a reference system into the research yard to whatever length is required and to develop the necessary ancillary measurement equipment and software for rapid realignment. We stress the word rapid because the favorable conditions of ground stability observed in the tunnel will not obtain in the yard; a region which will be subject to changes of loading and major diurnal temperature fluctuations.

We propose to equip every focussing element with an associated laser target station. (Version FFTF 34, for example, contains 17 Quads, FFTB-59 uses 29.) Flat field bending magnets, which in principle have loose transverse tolerances, will be placed by conventional means. We assume for the purpose of this proposal that sextupoles will be aligned and permanently fixed to their associated quadrupoles in a precision laboratory environment. The mechanical mounting of beam position monitors will be treated in a similar way.

Although there are more modern[15] methods, we believe this proposal is competitive, both technically and financially, for the following reasons:

1. A great deal of the required hardware already exists. This includes: the laser, its mounting, the input mirror box, some 16 Fresnel target actuators and their vacuum housings, some 600 ft of 10" vacuum pipe and bellows joints, the double targets to reference to the accelerator, a detector room with its CCD Camera and precision slide readout.
2. By virtue of the system's very large lever arm, it achieves the type of resolution required.
3. The existing mechanical parts can achieve the required repeatabilities. Engineering designs exist and additional stations can be manufactured from

existing drawings.

4. Because it is unlikely that the old BSY lenses will fit into the extended system perfectly, a new program for the so called artwork has already been written. The manufacture of new lenses by chemical machining is today about an order of magnitude less expensive than it was 25 years ago due to advances in microelectronics technology.

5. It is well to remember that in the micron world, steel behaves like butter. The existing designs of the housings attest to their stability and rugged resistance to abuse.

6. No matter what scheme is adopted for an optical reference line, the difficult problems of coordinate transfer must be solved.

At this moment of writing we are not ready to evaluate, with complete confidence, all the ingredients of the error budget for either the resolution or the accuracy of the system. On the basis of other investigators experiences[16] we believe that entering the micron world may present unexpected effects. We believe this fact is consistent with the exploratory nature of the Final Focus Test Beam's mission.

5. List of required R & D subprojects

We list below, in tabular form, a task list of development projects that will have to be carried out to make the proposed alignment system perform at the levels required. The type of money of 80% E,D &I.

Table II: Summary of R & D Subprojects for FFTB Alignment Proposal

Item	Est.Dev.Period (months or mm)	Est.Cost (k$)
1.Evaluate Mekometer Acquisition	3 m	done
2.Calculate new lenses	.5 mm	–
3.Evaluate new lens procurement	1	–
4.Design new station tooling	6 mm	38
5.Design new component tooling	6 mm	38
6.Design Arm Bridge	3mm -	19
7.Design Horizontal extensometer	6 mm	38
8.Design Hydrostatic Level System	6mm	38
9.Field Test "Arm" performance	4 m	–
10.Design new Vacuum enclosures	3 mm	19
11.Prepare Actuator Bid Package	2 mm	17
12.Prepare Lens Housing Bid Package	2 mm	17
13.Design component roll readout	2 mm	17
14.Prepare "Construction" Survey	2mm	17
15.Coordinate Tunnel Floor Design	–	–
16.Installation Drawings	1	6
17.Design Camera Demagnifier	4m / (2mm)	16
18.Design New Software Architecture	4m / (2mm)	16
19.Eng.Design of Component I&C	5 mm	34
20.Define Project Management Plan	1 mm	–
TOTALS		330

6. Proposed Production Budget Requirements

The following table lists the estimated efforts of producing the required hardware and installing it in the field. Only costs associated with the alignment system are included. The assumed number of quadrupoles is 29. The type of money is mostly M & S.

TABLE III. Summary of Production and Installation Estimates

Item	Time Span (months)	Est.Cost (k$)
1.Acquire Mekometer	3 m	90
2a.New Fresnel Artwork	1 m	1
2b.Procure Fresnel Lenses	3 m	10
3.Produce Station Tooling 5k/		150
4.Produce Component Tooling 5k/		150
5.Produce Arm Bridges 0.5k/		15
6a.Produce Extensometers 2k/		60
6b.Extensometer I & C		21
7a.Produce Levels 3k/		180
7b.Level I & C		60
8.Vacuum Enclosure Contract		96
9a.Actuator Contract		122
9b.Actuator I & C		6.6
10.Station Housing Contract		292
11a.Roll meters (7 units for bends)		6
11b.Roll I & C		14
12.Perform "Layout" Survey	2 mm	22
13."Calibrate" station tooling	60 hrs	7
14.Mount Housings and Vacuum Lines	7 mm	54
15.Install Actuators and Air lines	1 mm	7.4
16.Install all Temperature Readouts		10
17.Install laser and safety system		2
18.Est. Laserline and Repos. Stations		–
19.Perform Precision "Z" survey	.5 mm	5
20.Install Arms and Calib. Extens.	3 mm	30
21.Install and Checkout Level Systems	1 mm	10
22.I & C Wiring package and Coord.	3 mm	18
23.Perform initial component survey	3 mm	18
24.Management and Coordination	1.5 myrs	–
TOTALS		1,457

7. Proposed Manpower Requirements

This project, being similar to others in accelerator science, makes use of a broad range of skills resident in the laboratory. The requirements by category are listed in Table IV. We wish to call attention to the need of a mechanical-optical-electronic specialist whose experience in "micron-instrumentation" is essential to the successful conduct of this work.

TABLE IV: Manpower Requirements by Category

Category (no.)	Type of Funds	Effort (man months)
Survey Engineer (1)	E,D&I	
Mechanical Engineer (1)	E,D&I	
Instrument Specialist (1)	E,D&I	
I & C Engineer (1)	E,D&I	
I & C Coordinator (1)	B & H	
Surveyor (2)	B & H	
Designer Mech (2)	E,D& I	
Installation Coord.(1)	B & H	
Programmer (1)	E,D & I	
Physicist	E,D & I	

8. Acknowledgements

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2. K.Oide, "An optics design for the Final Focus Test Facility" Paper Q 18, Particle Accelerator Conference Chicago, March 1989.
3. Computer file MISALIGN OIDE C1, on disk JJM193, dated November 3 1988
4. The term "jitter" derives from the notion that high frequency errors are not correctable by conventional means. Since high frequency countermeasures have already been proposed for highly sensitive beams, the term jitter is probably a misnomer and should be more clearly defined.
5. For a general description of the SLAC linear accelerator laser alignment system see: R.B.Neal " The Stanford Two Mile Accelerator" Benjamin, New York, 1968 Lib.Congress Cat Card 68-23364, Chapter 22, page 821 - 885, Support and Alignment. This chapter also contains a discussion of the BSY system. More readily available is W.B.Herrmannsfeldt et al. "Precision Alignment Using a System of Large Rectangular Fresnel Lenses", Applied Optics, Vol.7,p995,(1968)
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BEAM SWITCHYARD CROSSECTION

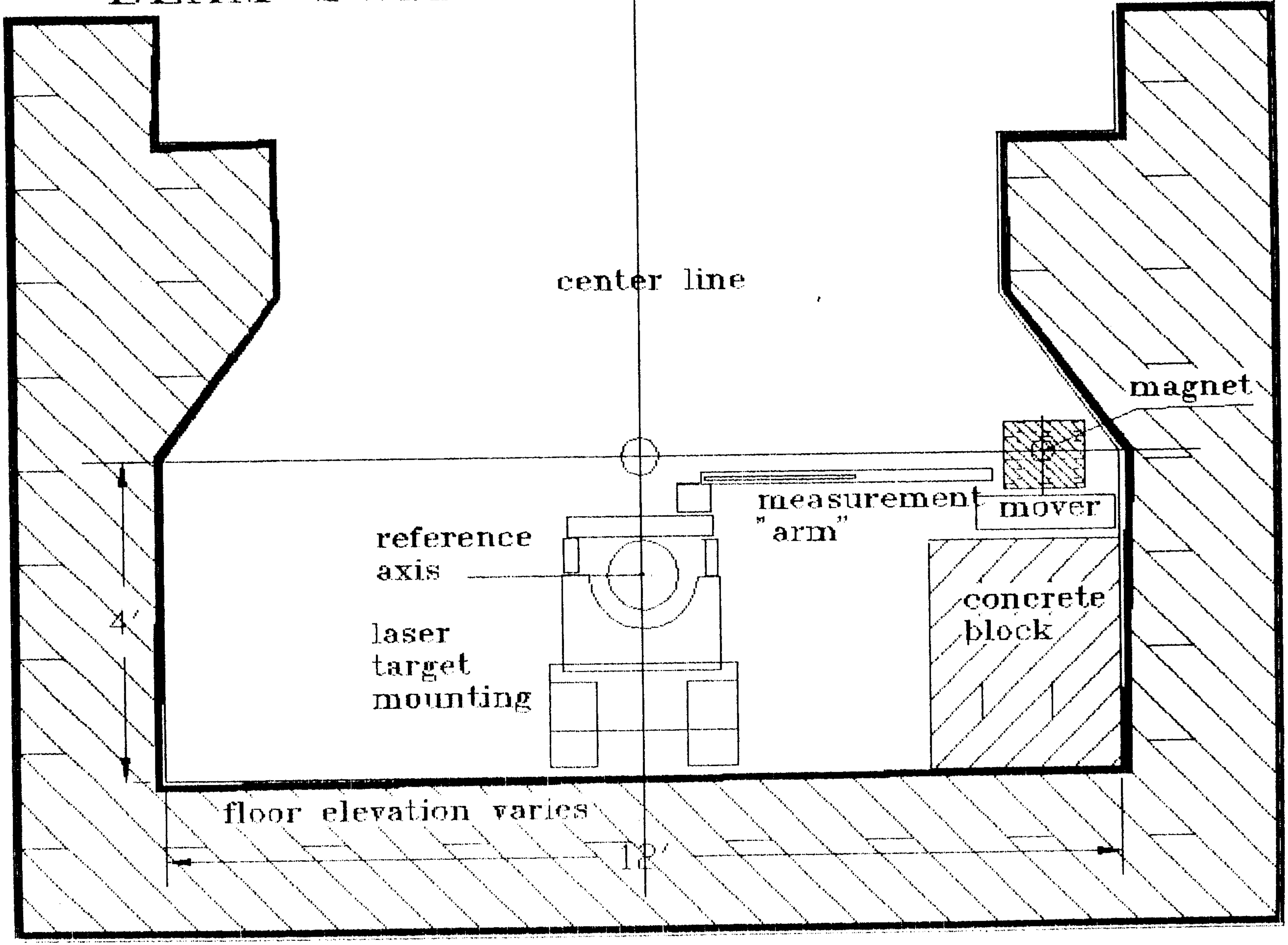


FIG.1

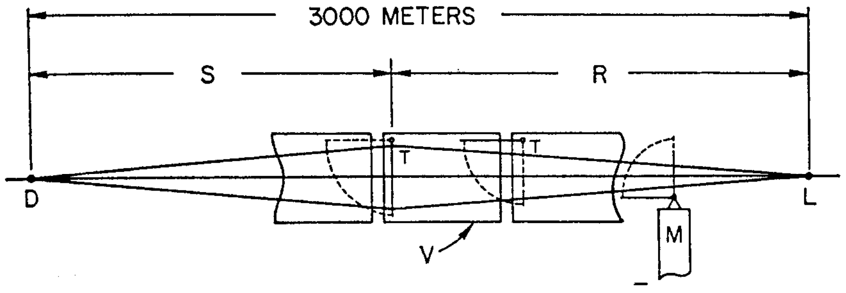


FIG. 2 Schematic illustration of the SLAC alignment system. A typical target *T*, which is actually a rectangular Fresnel lens, focuses the laser light source *L* to an image at the detector *D*. There are 294 alignment targets and three monument targets such as at *M*, which are attached to deep pillars. *V* is the 60-cm diam vacuum pipe, 12 m long.

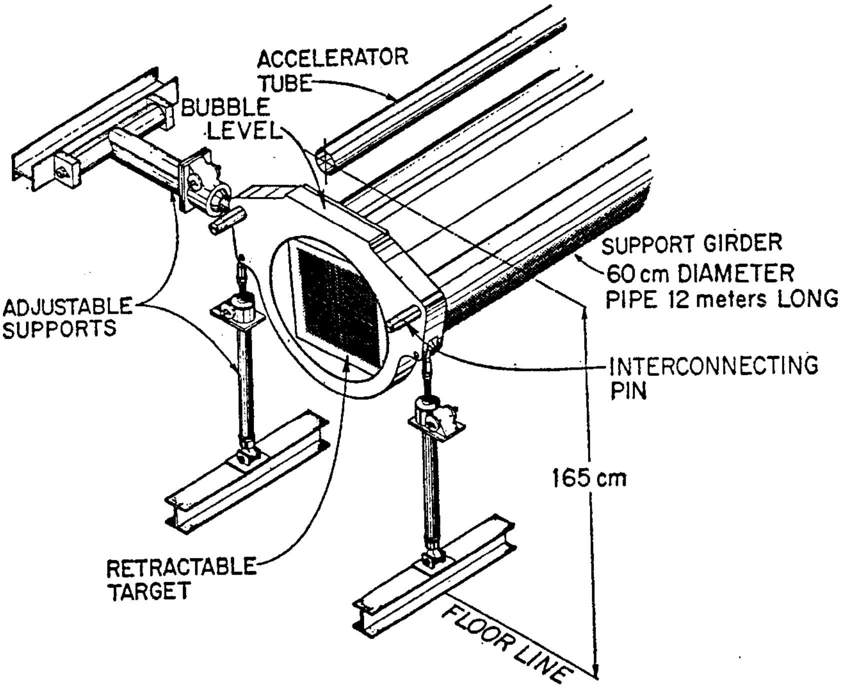


FIG. 3 The mounting arrangement at the target end of each accelerator support girder. The target is shown in the inserted position. When retracted, the target is positioned horizontally along the top of the pipe.

Diffraction limited width of image

$w = \frac{\lambda s}{D}$, leverage $\frac{\Delta x'}{\Delta x} = \frac{l}{r} = \frac{r+s}{r}$

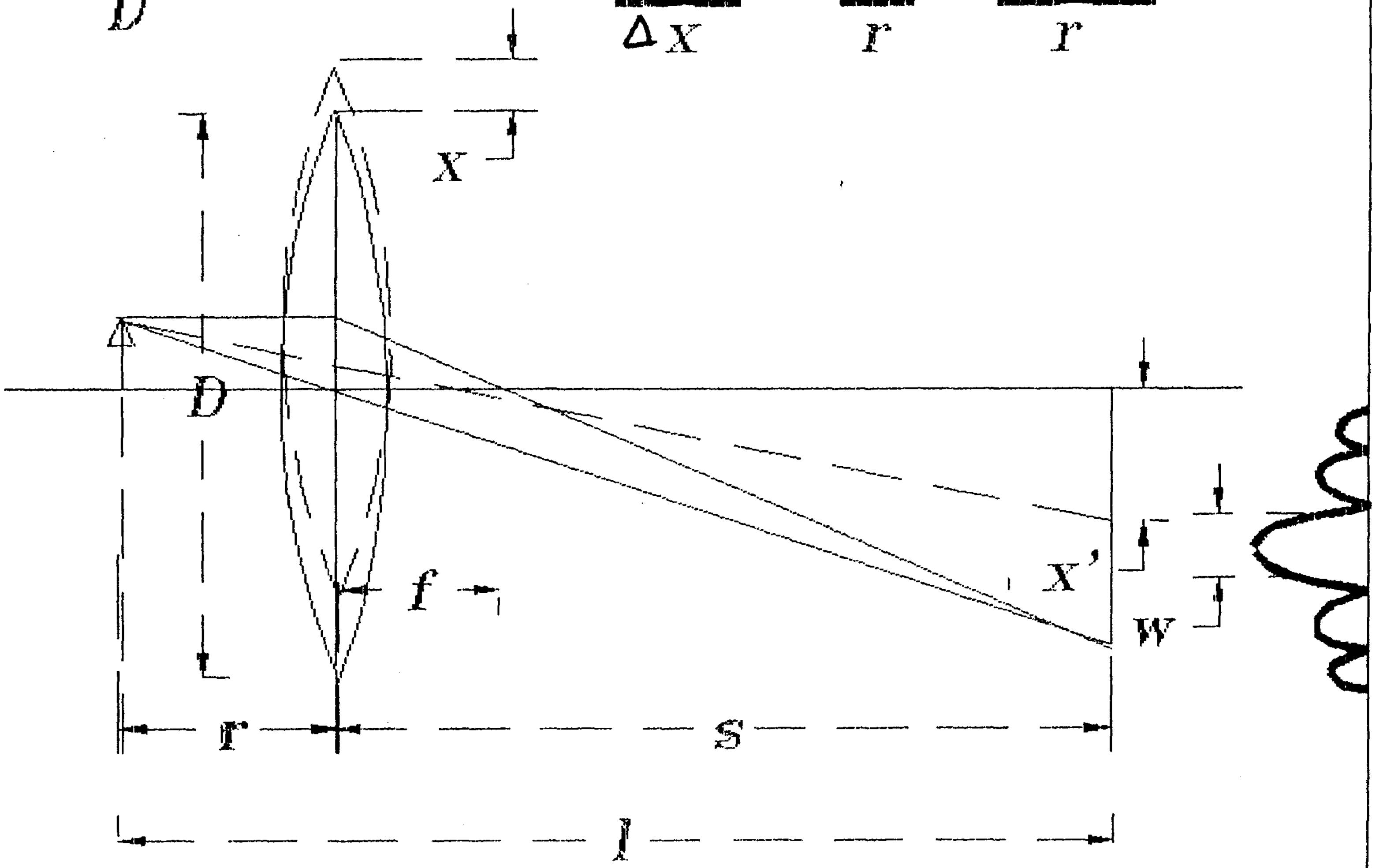
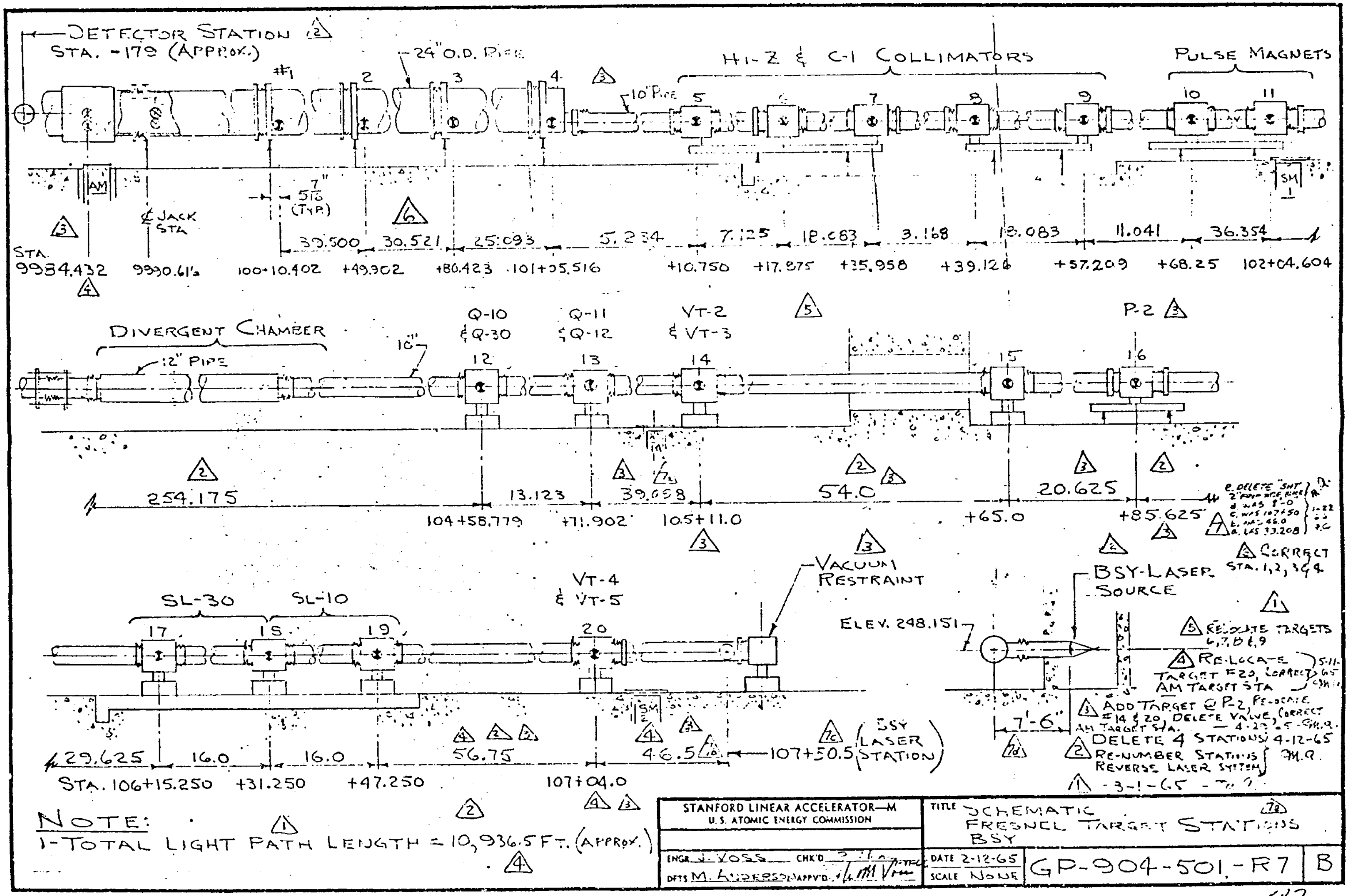


FIG.4


DETECTOR STATION
STA. -179 (APPROX.)
24" O.D. PIPE
10" PIPE
HI-Z & C-1 COLLIMATORS
PULSE MAGNETS
#1
2
3
4
5
6
7
8
9
10
11
AM
SM 1
℄ JACK STA
7" 5 1/16 (TYP)
STA.
9984.432
9990.61
100+10.402
+49.902
+80.423
101+05.516
+10.750
+17.875
+35.958
+39.126
+57.209
+68.25
102+04.604
39.500
30.521
25.093
5.234
7.125
18.083
3.168
18.083
11.041
36.354
DIVERGENT CHAMBER
12" PIPE
10"
Q-10 & Q-30
Q-11 & Q-12
VT-2 & VT-3
P-2
12
13
14
15
16
254.175
13.123
39.058
54.0
20.625
104+58.779
+71.902
105+11.0
+65.0
+85.625
e. DELETE "SNT 2" ...
d. WAS 8'-0
c. WAS 107+50
b. WAS 46.0
a. WAS 33.208
CORRECT STA. 1, 2, 3 & 4
SL-30
SL-10
VT-4 & VT-5
VACUUM RESTRAINT
17
18
19
20
SM 2
29.625
16.0
16.0
56.75
46.5
107+50.5
(BSY LASER STATION)
STA. 106+15.250
+31.250
+47.250
107+04.0
ELEV. 248.151
BSY-LASER SOURCE
7'-6"
RELOCATE TARGETS 6, 7, 8 & 9
RE-LOCATE TARGET #20, CORRECT AM TARGET STA 5-11-65
ADD TARGET @ P-2, RE-LOCATE #14 & 20, DELETE VALVE, CORRECT AM TARGET STA. — 4-23-65
DELETE 4 STATIONS 4-12-65
RE-NUMBER STATIONS
REVERSE LASER SYSTEM
3-1-65
NOTE:
1-TOTAL LIGHT PATH LENGTH = 10,936.5 FT. (APPROX.)
STANFORD LINEAR ACCELERATOR—M
U.S. ATOMIC ENERGY COMMISSION
TITLE SCHEMATIC FRESNEL TARGET STATIONS BSY
ENGR J. VOSS
CHK'D
DFTS M. ANDERSON
APPV'D
DATE 2-12-65
SCALE NONE
GP-904-501-R7
B

nFR7

FIG.5

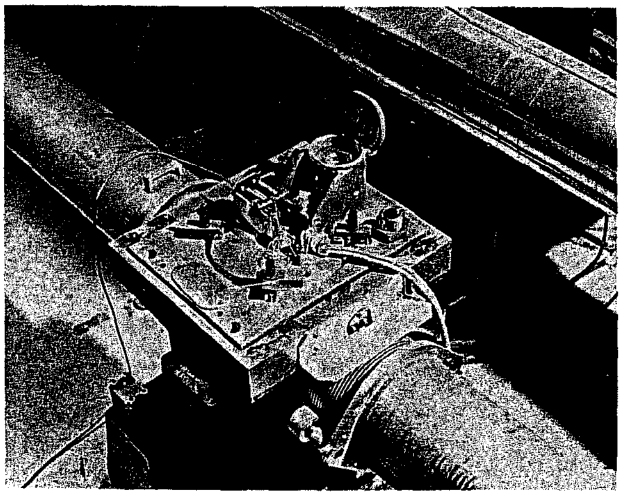
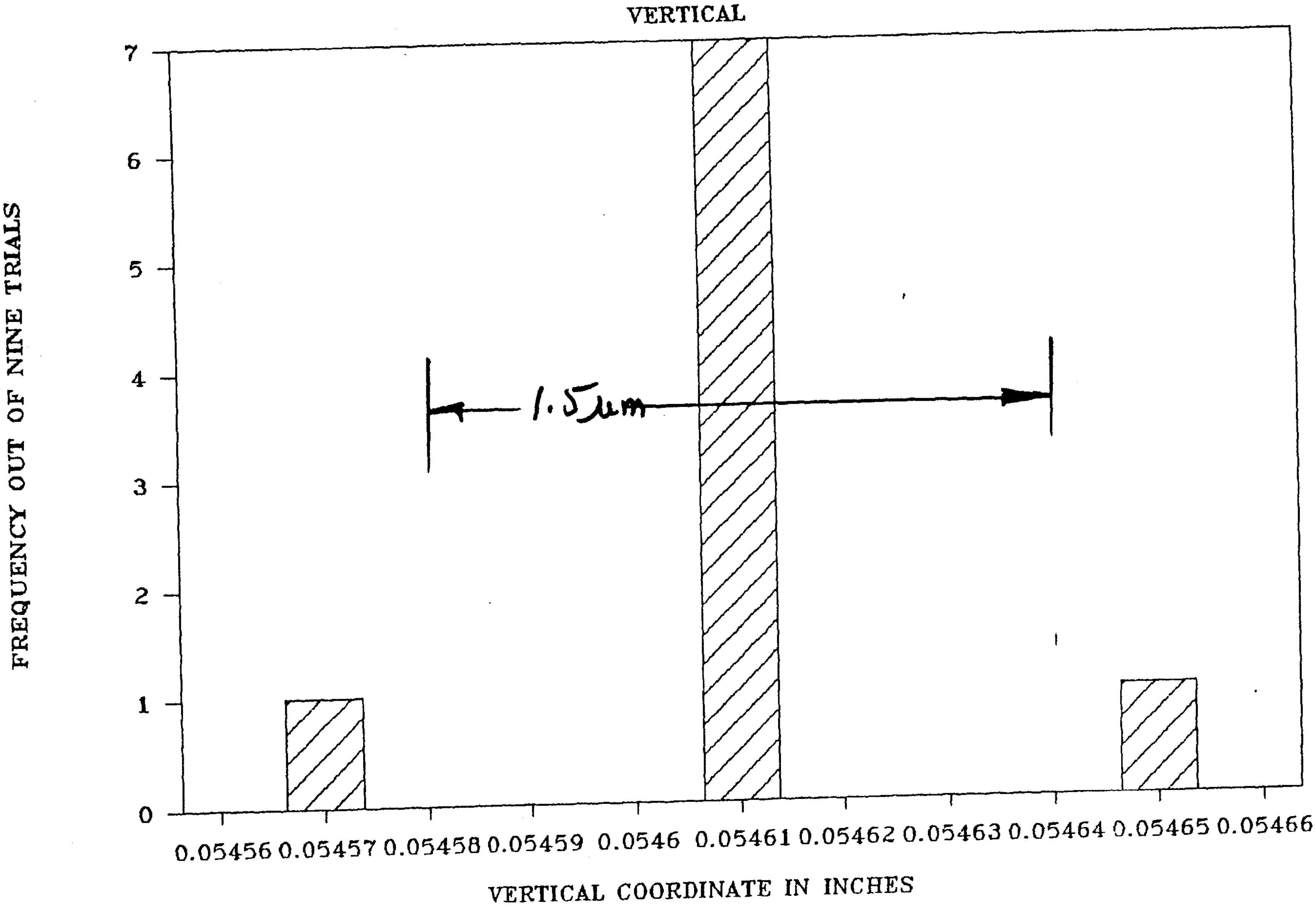


FIG.6 Alignment equipment on laser target stand.

BSY LASER TARGET REPEATABILITY TEST*



* SPARE UNIT

FIG.7

BSY LASER TARGET REPEATABILITY TEST*

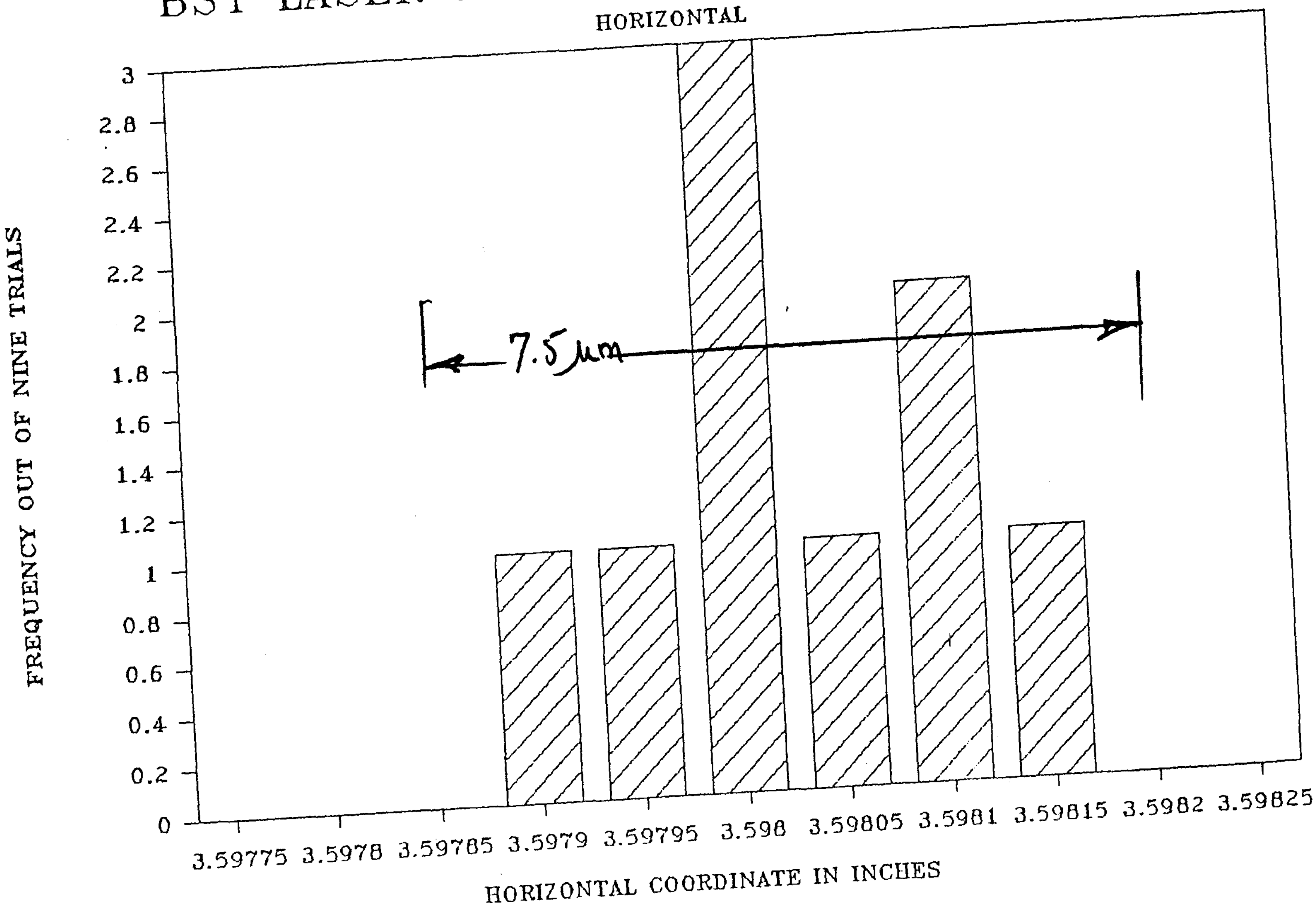


FIG.8

* SPARE UNIT

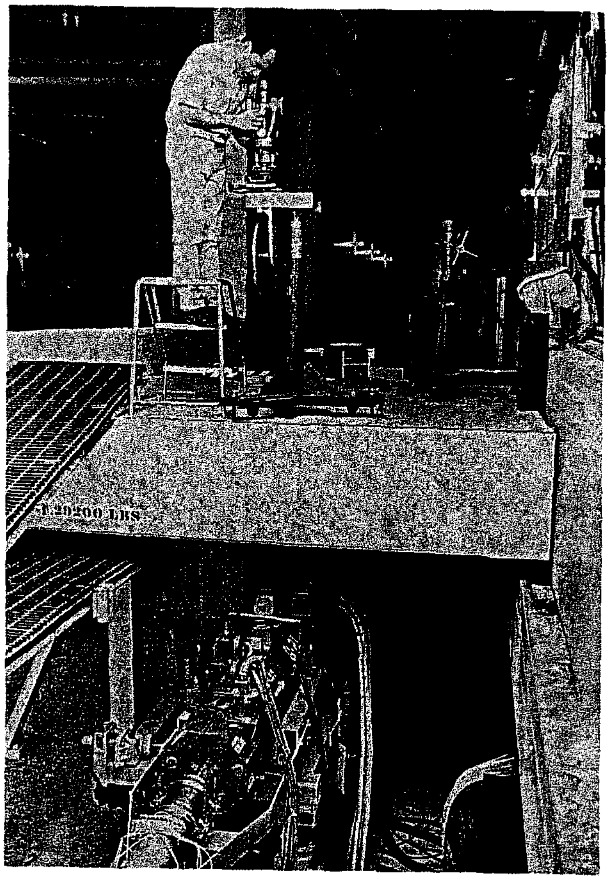


FIG.9 Alignment of beam switchyard components from second level shielding blocks.

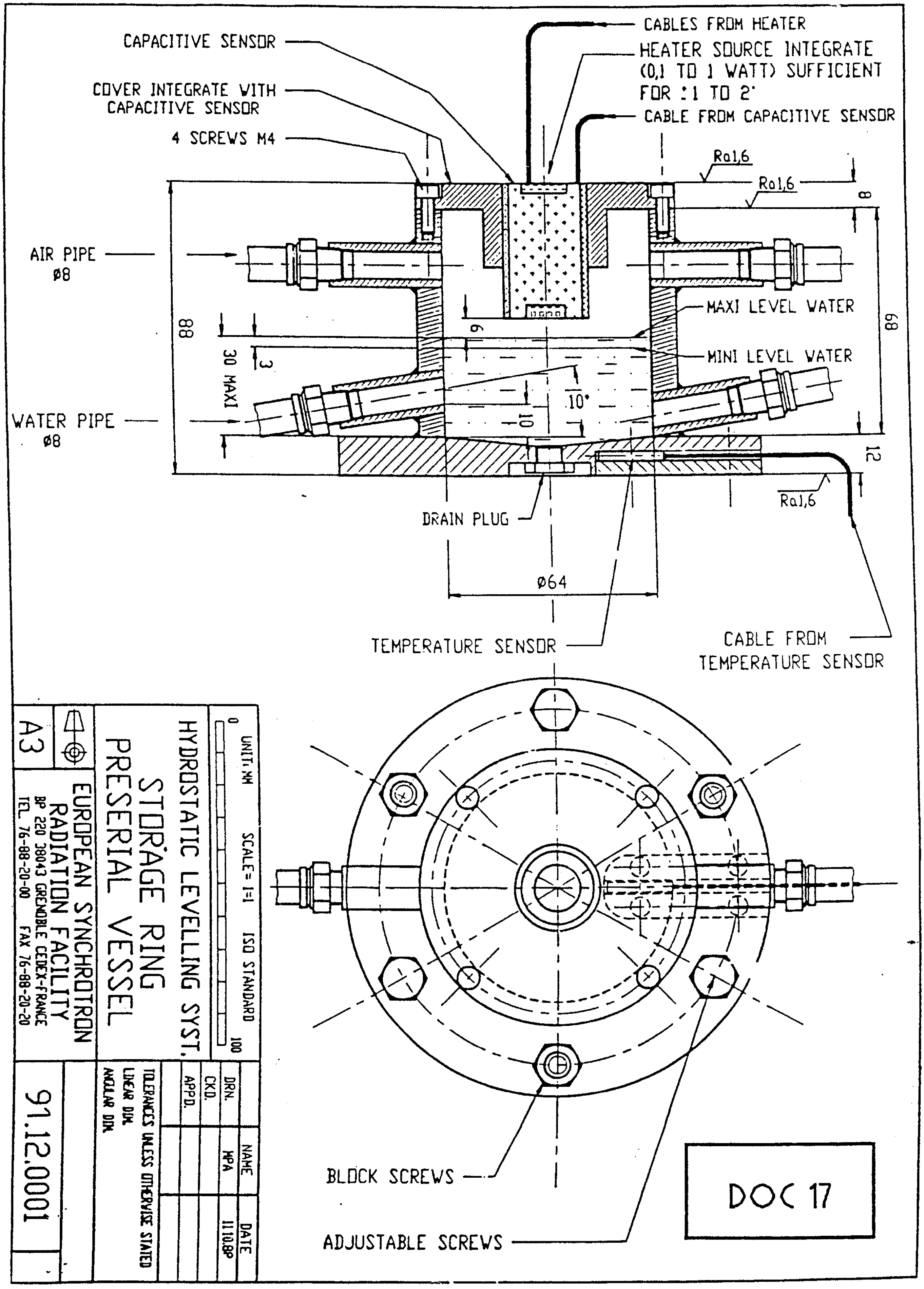
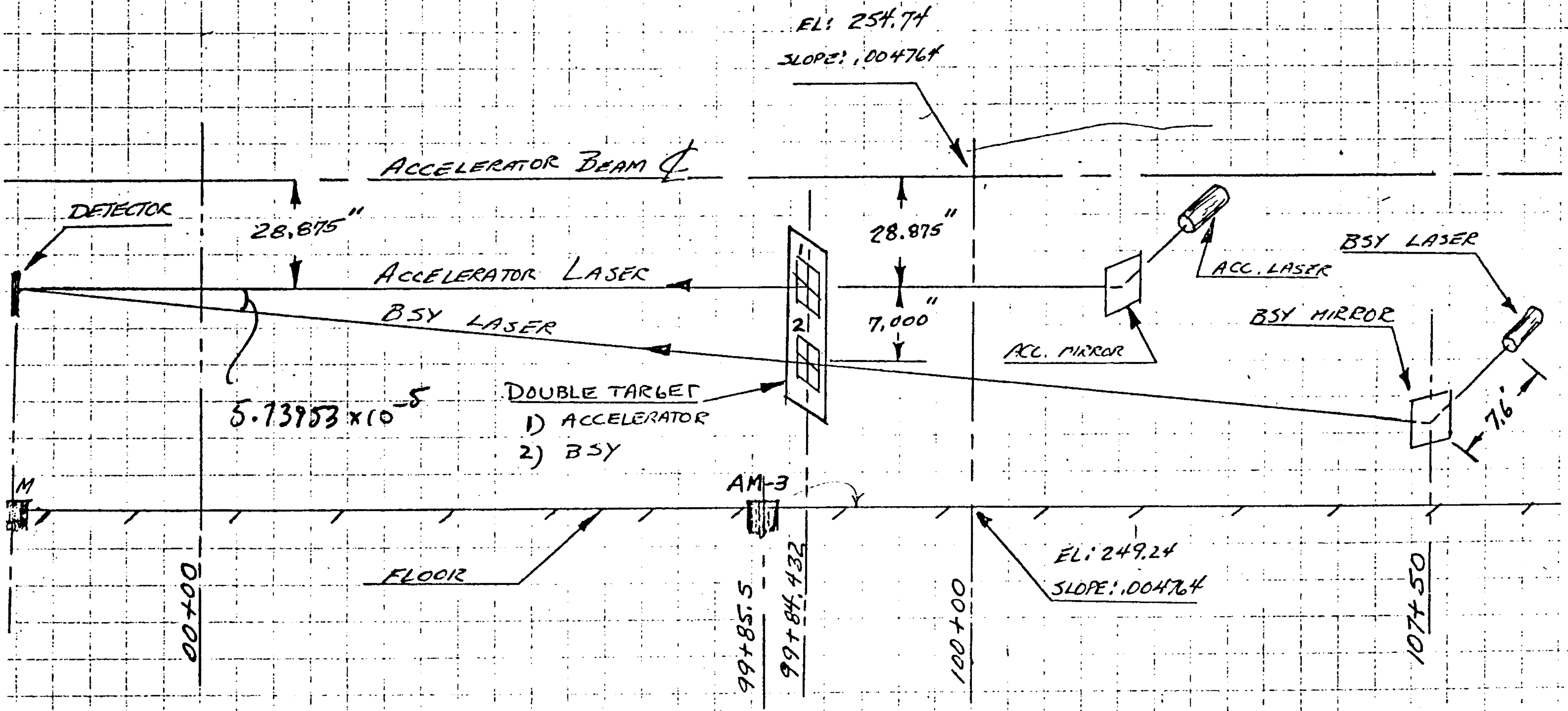

CAPACITIVE SENSOR
COVER INTEGRATE WITH CAPACITIVE SENSOR
4 SCREWS M4
CABLES FROM HEATER
HEATER SOURCE INTEGRATE (0,1 TO 1 WATT) SUFFICIENT FOR :1 TO 2°
CABLE FROM CAPACITIVE SENSOR
Ra1,6
Ra1,6
8
AIR PIPE
Ø8
88
6
30 MAXI
3
MAXI LEVEL WATER
MINI LEVEL WATER
69
10°
10
WATER PIPE
Ø8
12
Ra1,6
DRAIN PLUG
Ø64
TEMPERATURE SENSOR
CABLE FROM TEMPERATURE SENSOR
BLOCK SCREWS
ADJUSTABLE SCREWS
DOC 17
UNIT: MM
SCALE= 1:1
ISO STANDARD
0
100
HYDROSTATIC LEVELLING SYST.
STORAGE RING
PRESERIAL VESSEL
EUROPEAN SYNCHROTRON RADIATION FACILITY
BP 220 38043 GRENOBLE CEDEX-FRANCE
TEL 76-88-20-00 FAX 76-88-20-20
A3
NAME
DATE
DRN.
MPA
1110.89
CKD.
APPD.
TOLERANCES UNLESS OTHERWISE STATED
LINEAR DIM.
ANGULAR DIM.
91.12.0001

FIG.10



BSY LASER SCHEMATIC

John Voss
9/24/65

FIG.11

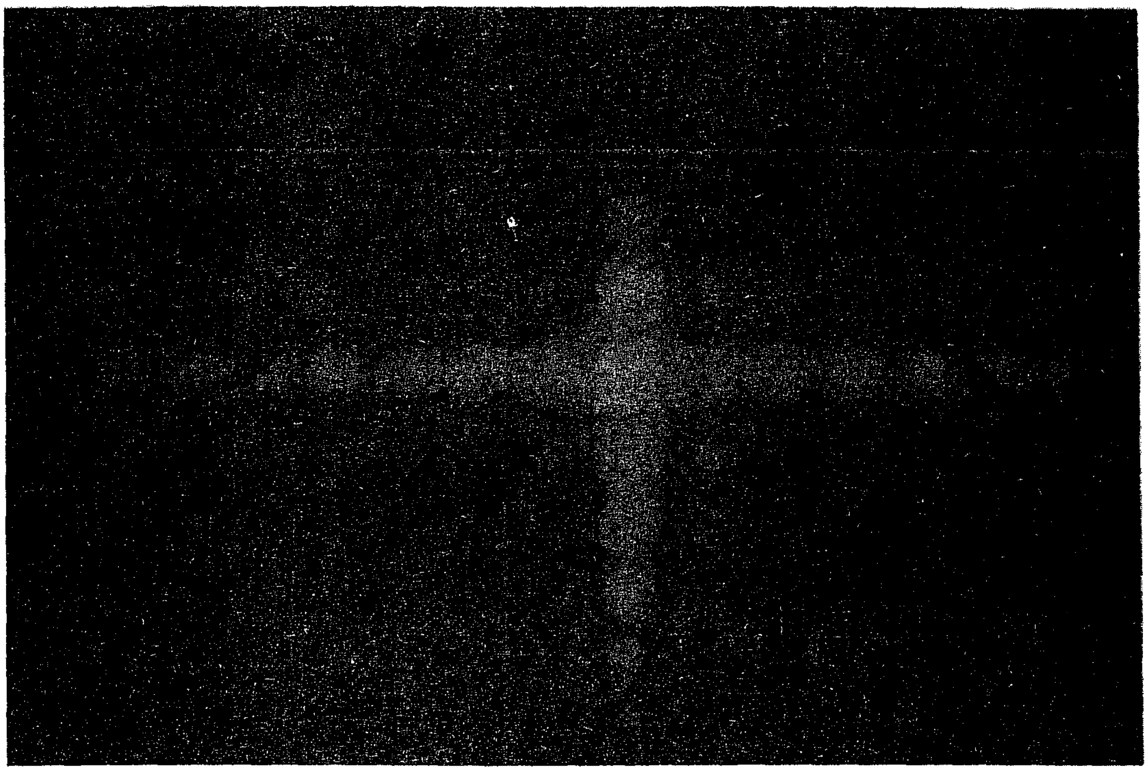


FIG.12

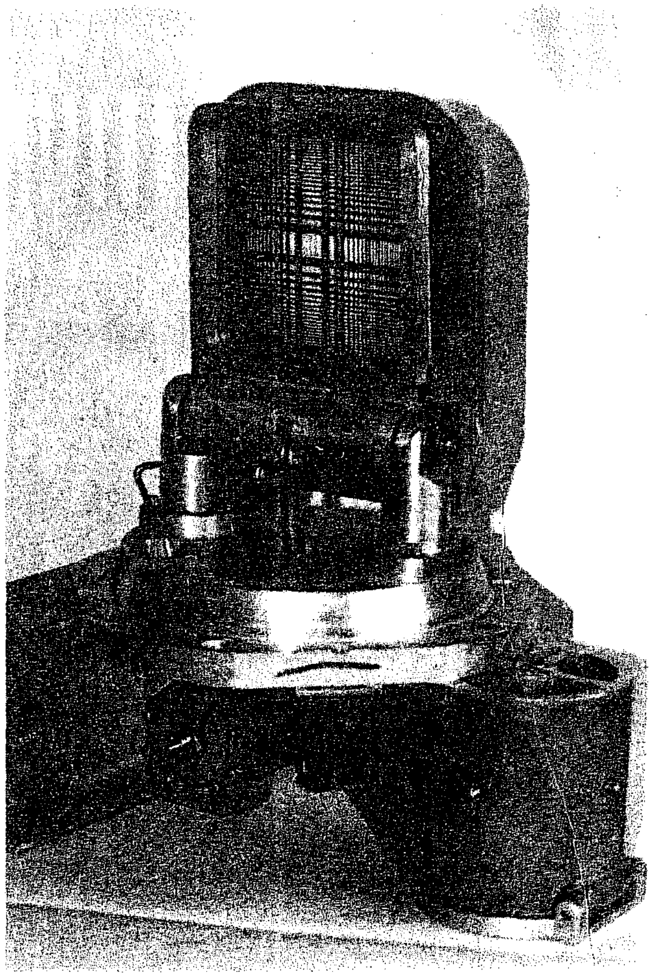


FIG.13

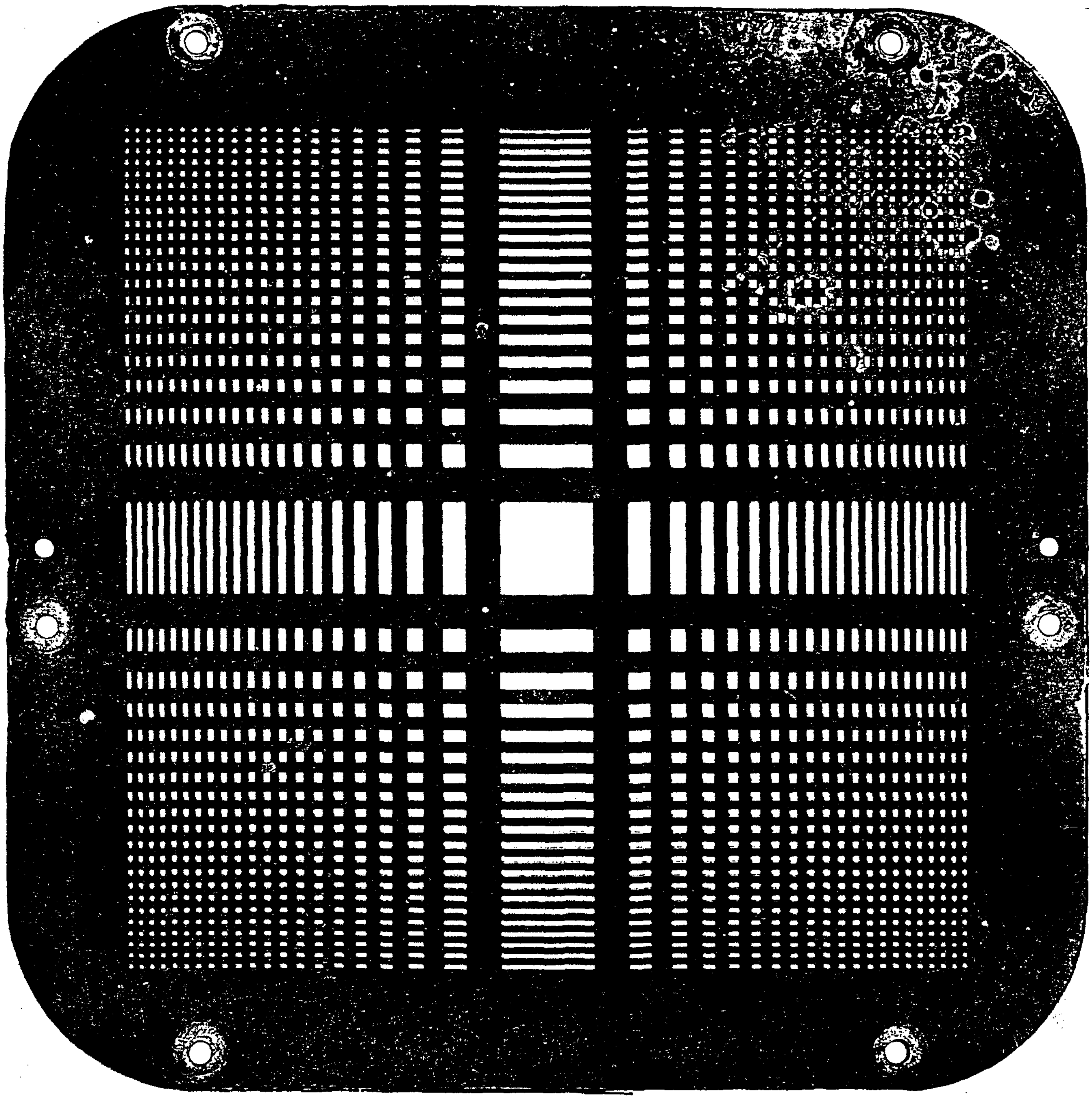


FIG.14

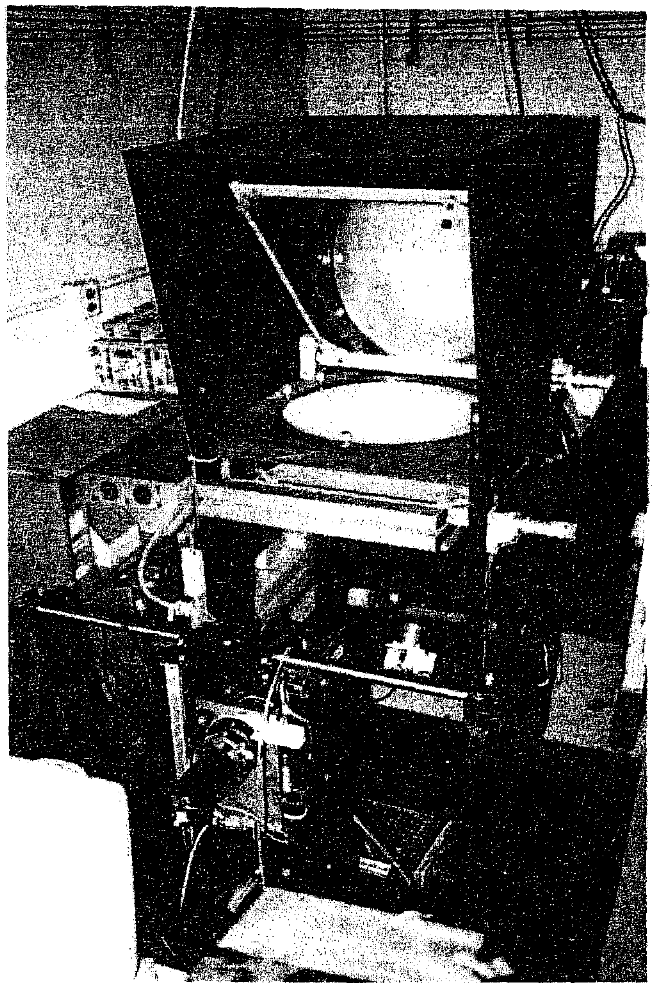


FIG.15

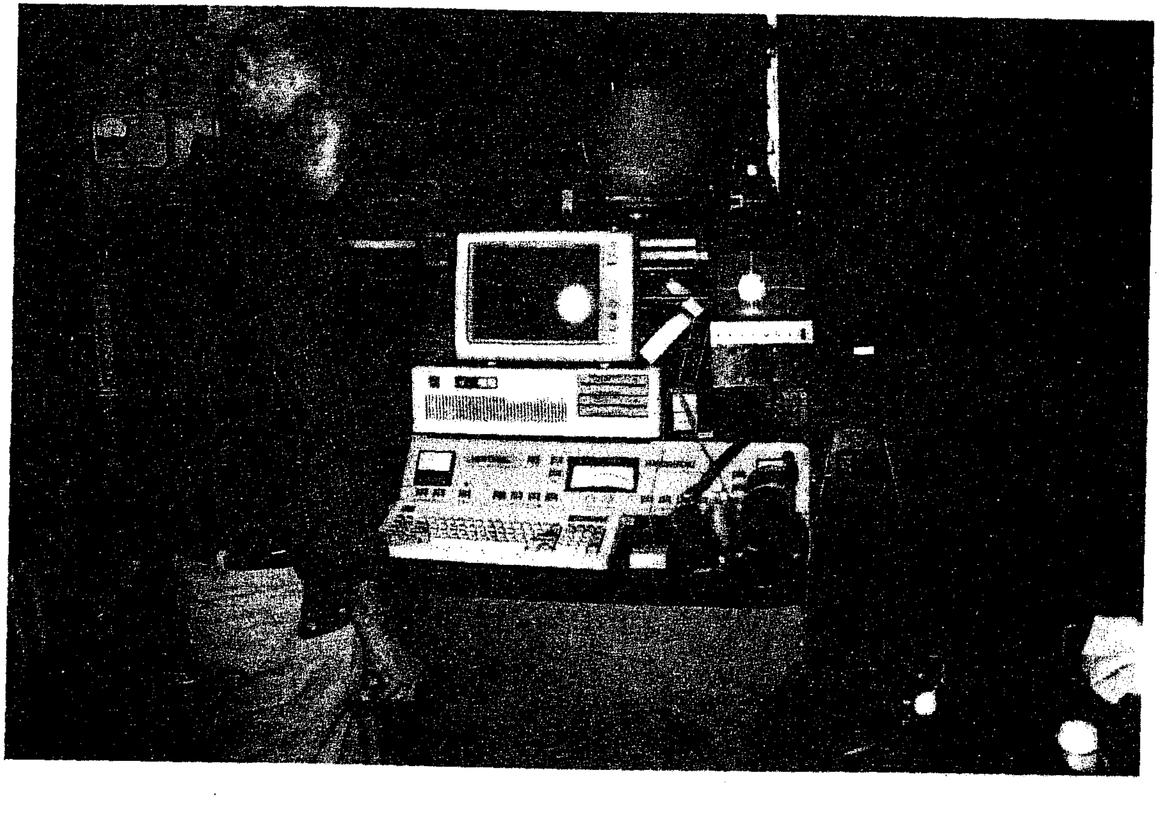


FIG.16