SLAC-PUB-5506
March 1991
(M)

COORDINATE MEASUREMENT MACHINES AS AN ALIGNMENT TOOL *

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1. ABSTRACT

In February of 1990 the Stanford Linear Accelerator Center (SLAC) purchased a LEITZ PM 12-10-6 CMM (Coordinate measurement machine). The machine is shared by the Quality Control Team and the Alignment Team.

One of the alignment tasks in positioning beamline components in a particle accelerator is to define the component's magnetic centerline relative to external fiducials. This procedure, called fiducialization, is critical to the overall positioning tolerance of a magnet. It involves the definition of the magnetic center line with respect to the mechanical centerline and the transfer of the mechanical centerline to the external fiducials. To perform the latter a magnet coordinate system has to be established. This means defining an origin and the three rotation angles of the magnet. The datum definition can be done by either optical tooling techniques or with a CMM. As optical tooling measurements are very time consuming, not automated and are prone to errors, it is desirable to use the CMM fiducialization method instead. The establishment of a magnet coordinate system based on the mechanical center and the transfer to external fiducials will be discussed and presented with 2 examples from the Stanford Linear Collider (SLC).

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

Invited talk presented at the 1991 ACSM/ASPRS Annual Convention:
Coordinate Measurement Systems Committee
Baltimore,MA, March 25-29, 1991

2. PRESENTATION

2.1. Existing measurement services at SLAC

1.) Optical tooling

2.) Theodolite measurement systems (ECDS, SIMS): 30 - 50 microns under best conditions

3.) Coordinate measurement machine : 0.8 microns +- 2.5 ppm

Optical tooling has been the prefered method to establish a coordinate system based on the mechanical center of a magnet.

2.2. General features of a high precision CMM

2.2.1. Machine

(see Figure 1)

1.) X,Y,Z axis

2.) Moving table, 1 or 2 dimensions

3.) Scales or laser interferometers

4.) Accuracy, resolution and repeatability

- should be order of magnitude better than tightest tolerance. This is impossible for tolerances of 2.5 Microns (0.0001 in).
- sub- or near micron accuracy throughout measuring volume. Accuracy quoted linearly and volumetrically. It is volumetric accuracy that is important.
- resolution of 0.1 to 0.01 microns.
- repeatablity: ~ 0.2 microns.

2.2.2. Software and computer

1.) Fit geometric forms: circle & circularity,sphere & sphericity, plane & flatness, etc.

2.) Deviation from nominal profile

3.) Interrelation between forms, e.g. intersection of 2 planes

4.) scanning of continuous profiles

5.) determine virtual points

6.) Coordinate transformations

7.) Full access to software

8.) All data stored on harddisk

9.) Hard copy: print out & plots

10.) Link to VMS

11.) Link to CNC machine tools and CAD/CAM

2.2.3. Usage

1.) Manual operation using joysticks: for first part inspection and quick jobs

2.) Automatic operation for repeated measurements

- Teach mode: guide machine through one complete measurement cycle. It remembers how to measure the part.
- Program mode: relatively easy as we have nominal coordinates for nearly everything; could use NC tapes.

3.) Probe ~ 40 cm into interior, e.g. beam pipe

4.) Variable probe pressure: possibility of measuring even soft-copper parts with milligram pressure.

2.2.4. Accessories

1.) Optional video: can combine video and probe measurements

2.) Optional rotary table

2.3. Advantages of CMM measurements vs. optical tooling and theodolites

1.) Shorter measurement time frame

2.) More accurate

3.) Documented with program listings and output listings

4.) Repeatable

5.) Automated

6.) Not dependent on individual targets. Work with surfaces

7.) Scan option

2.4. Examples

2.4.1. Final focus Quadrupole magnets

2.4.1.1. Element description

Quadrupole magnets are generally used for focusing or defocusing a particle beam along it's path. These particular magnets are destined to be installed in final focus section near the collider hall. (See Figures 2-5)

2.4.1.2. Splitplane coordinate system

All optical tooling measurements used a coordinate system defined by the magnet splitplanes. To make a direct comparison with the optical tooling data the CMM had to duplicate the splitplane magnet coordinate system. Each magnet consisted of 4 quadrants bolted together. Along the edges triangular shaped grooves were machined. This allowed us to probe the splitplanes and establish a coordinate system with the ZX plane established by the horizontal surfaces and the ZY plane perpendicular through the vertical surfaces. Z=0 in the center of the magnet established by the symmetry plane between front and back faces of magnet. The tooling ball coordinates measured in this splitplane coordinate system agreed with the optical tooling coordinates within 0.001 inches.

2.4.1.3. Pole tip based coordinate system

Further, we established a different magnet coordinate system based on the pole tips of each quadrant. Because a particle beam actually "sees" the pole tips this seemed to be a more realistic way to build our magnet coordinate system. For this purpose we scanned each pole tip from the front and from the back. From the 4 scans of the front and the back the extreme points in respect to their closest distance were extracted from the scan data and collected into a cylinder element. The resulting cylinder axis represented the Z-axis. The direction of ZY plane was defined by the normal vector of the horizontal splitplane surfaces. The X-axis follows the right hand rule. The resulting tooling ball coordinates were compared to the splitplane coordinate system data. Individual coordinates differ by as much as 0.004 inches. Magnetic data will be compiled to determine which system best represents the quads' magnetic properties.

2.4.1.4. Benefits

By comparing the time and the manload required to fiducialize a magnet, the CMM is clearly the choice for operations. With optical tooling 2 people are working for half a day on each magnet.

With the CMM, one person can measure a magnet in less than 1 hour if the measurement program is established. With optical tooling we couldn't scan the pole tips.

2.4.2. Positron target

2.4.2.1. Element description

The positron target is a new generation of a high power positron source. (See Figures 6-7).

- Trolling motion
- The beam hits the target ~0.125 [IN] from the outside edge.
- The material is a Tungsten alloy which when hit by an electron beam creats pairs of electrons and positrons. The positrons are collected with the flux concentrator.
- The target has to rotate otherwise it becomes too hot.
- The maximum deviation in a full revolution from a perfect circle < 0.032 [IN]

2.4.2.2. Shaft coordinate system

The target coordinate system was established in the following manner:

- Target measured in 6 positions as circles. Circle centers collected into a plane -> XY plane
- Shaft measured. ZY plane through shaft. X-axis follows right hand rule.

By comparing the shaft direction vector to the plane normal vector (made up of the target posistions) it was obvious that the Cam was bent. The target cam had to be reworked and would have been unoperational if it would have been installed in the tunnel.

2.4.2.3. Benefits

To fiducialize a complicated element like the positron target with optical tooling would have been a week's task for 2 people. The problem with the bent cam would have gone undetected. The whole process of measurement on the CMM took 1 man half a day. As several targets had to be measured several times, each run thereafter lasted less than 1 hour including the acquisition of an object coordinate system.

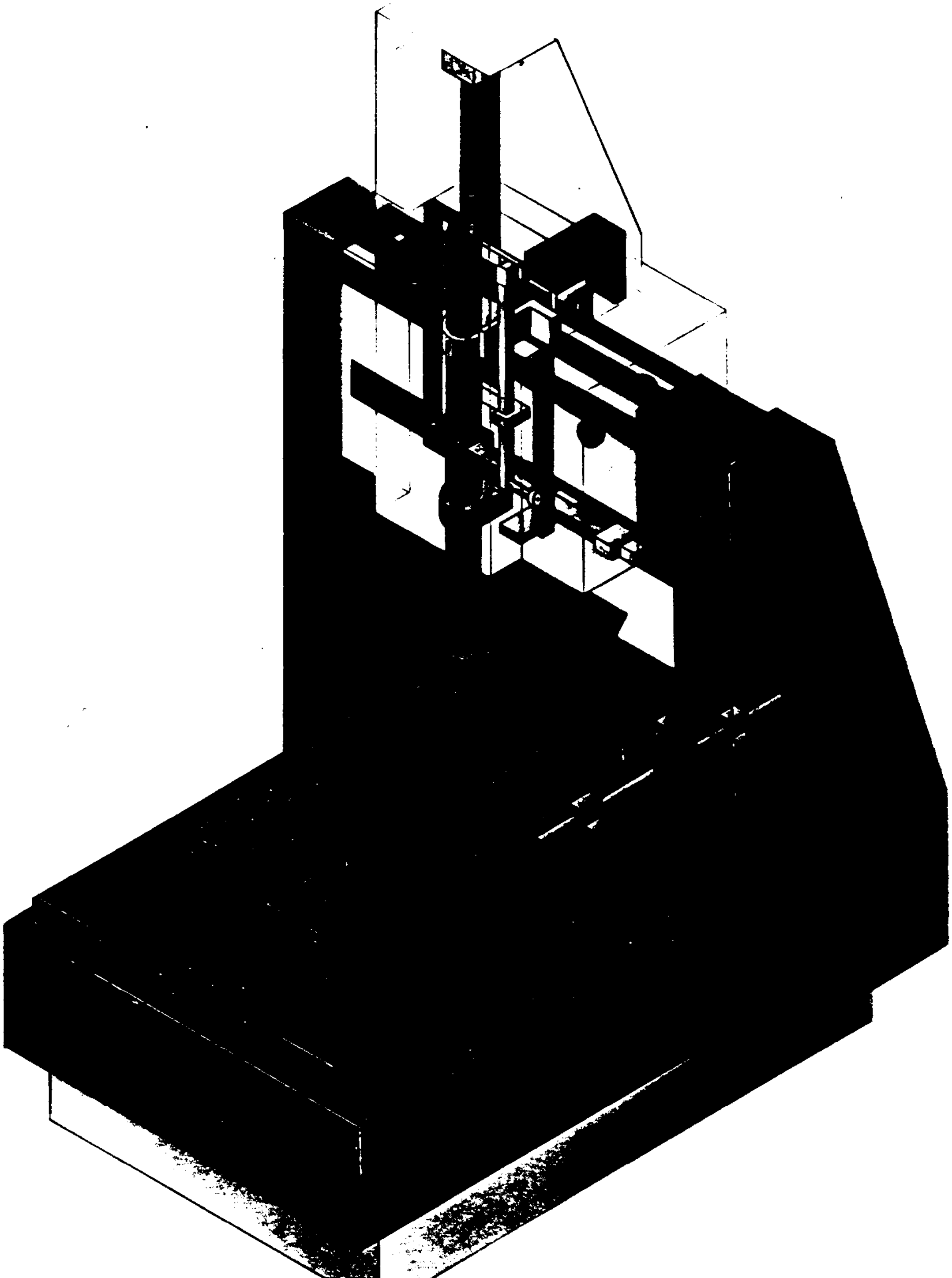
2.5. Future plans

1.) Incorporate theodolite measurements into CMM operations

2.) Incorporate video measurements

FIGURE CAPTIONS

Figure 1:	Bearings,drives and measurement systems of a CMM
Figure 2 - 4 :	Quadrupole magnet
Figure 5:	Scan of the quadrupole poletips
Figure 6:	Positron target trolling mechanism
Figure 7:	Positron target complete module assembly



Bearings, drives and measurement systems of a PMM

Fig. 1

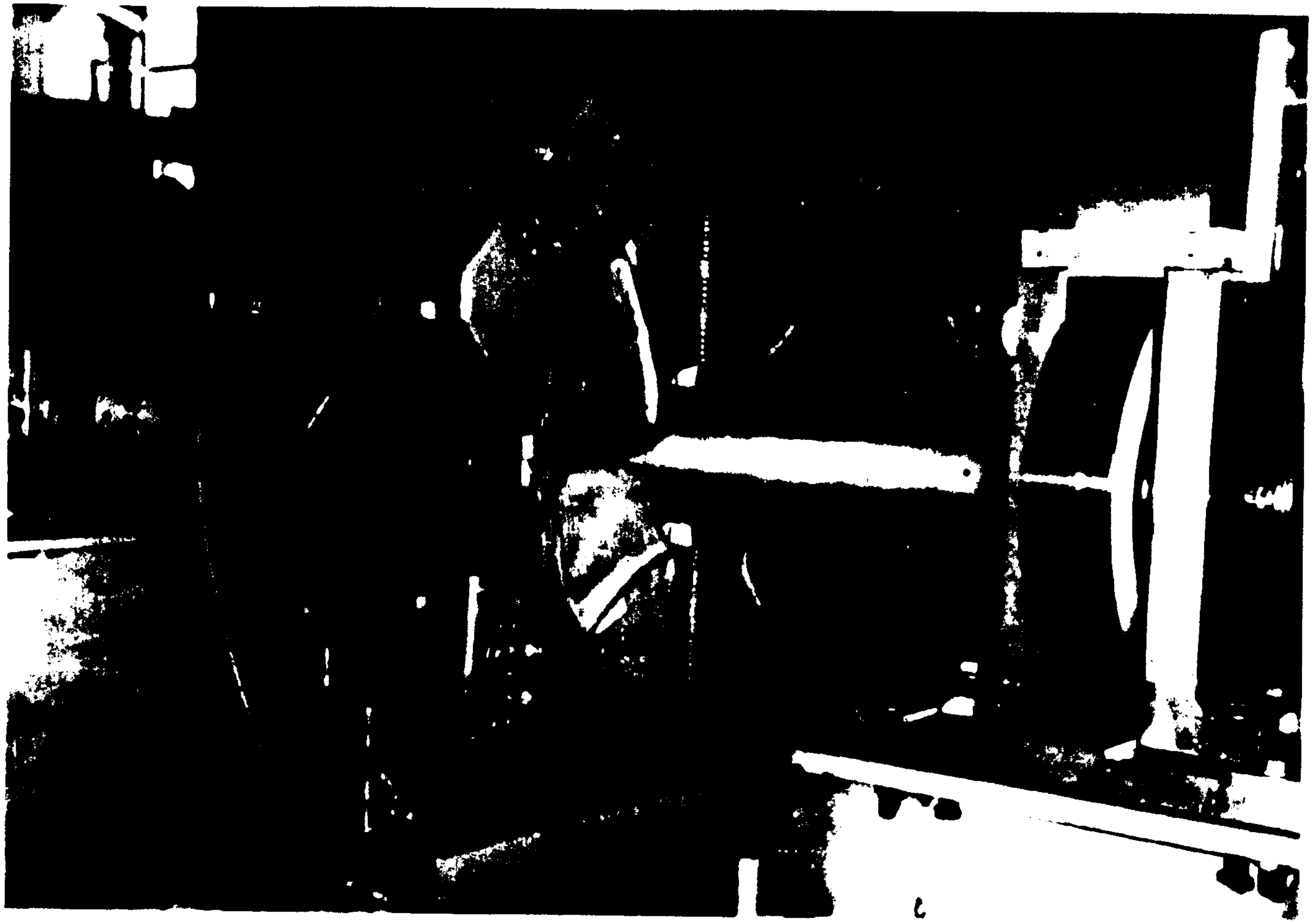


Fig. 2

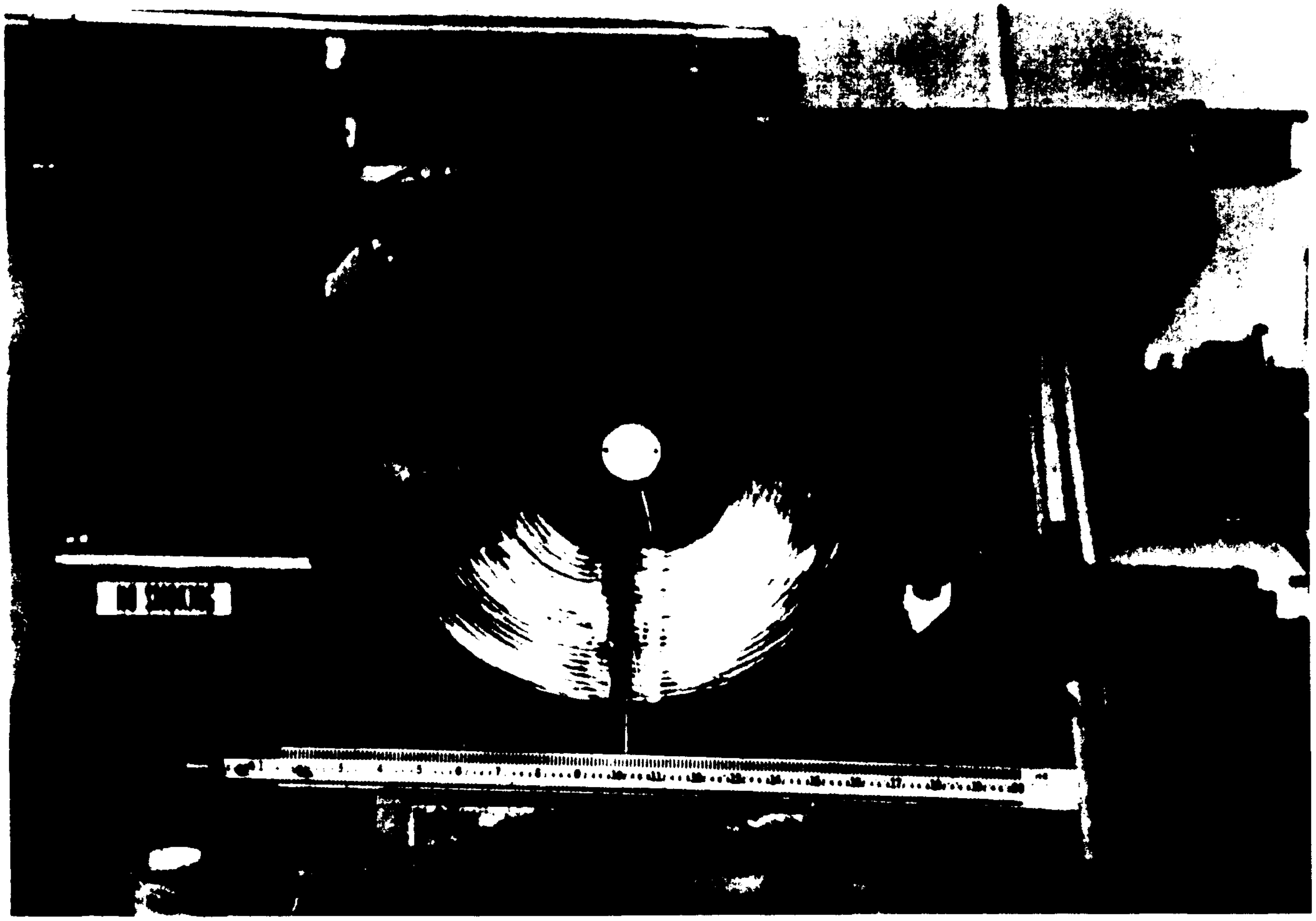
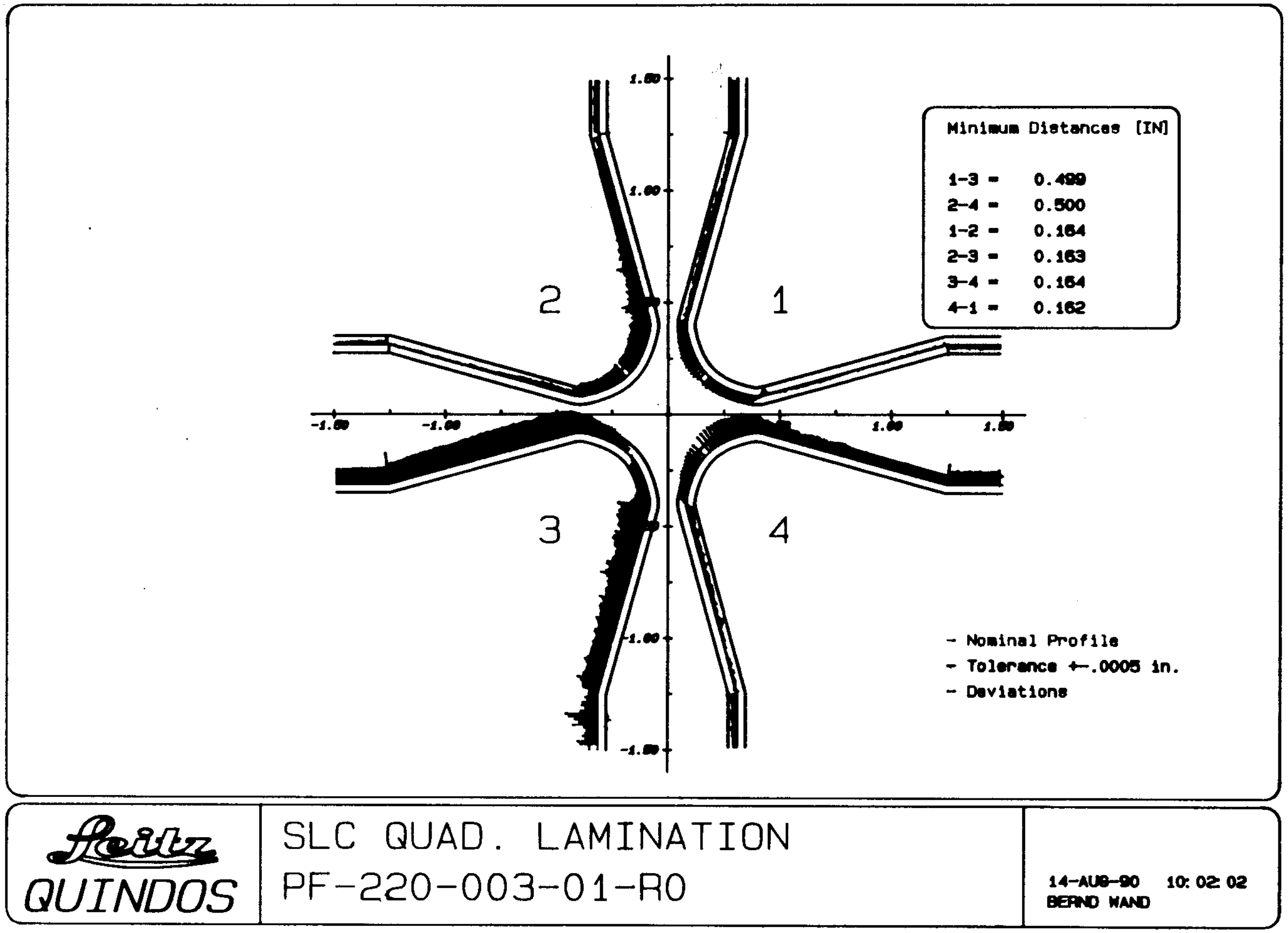


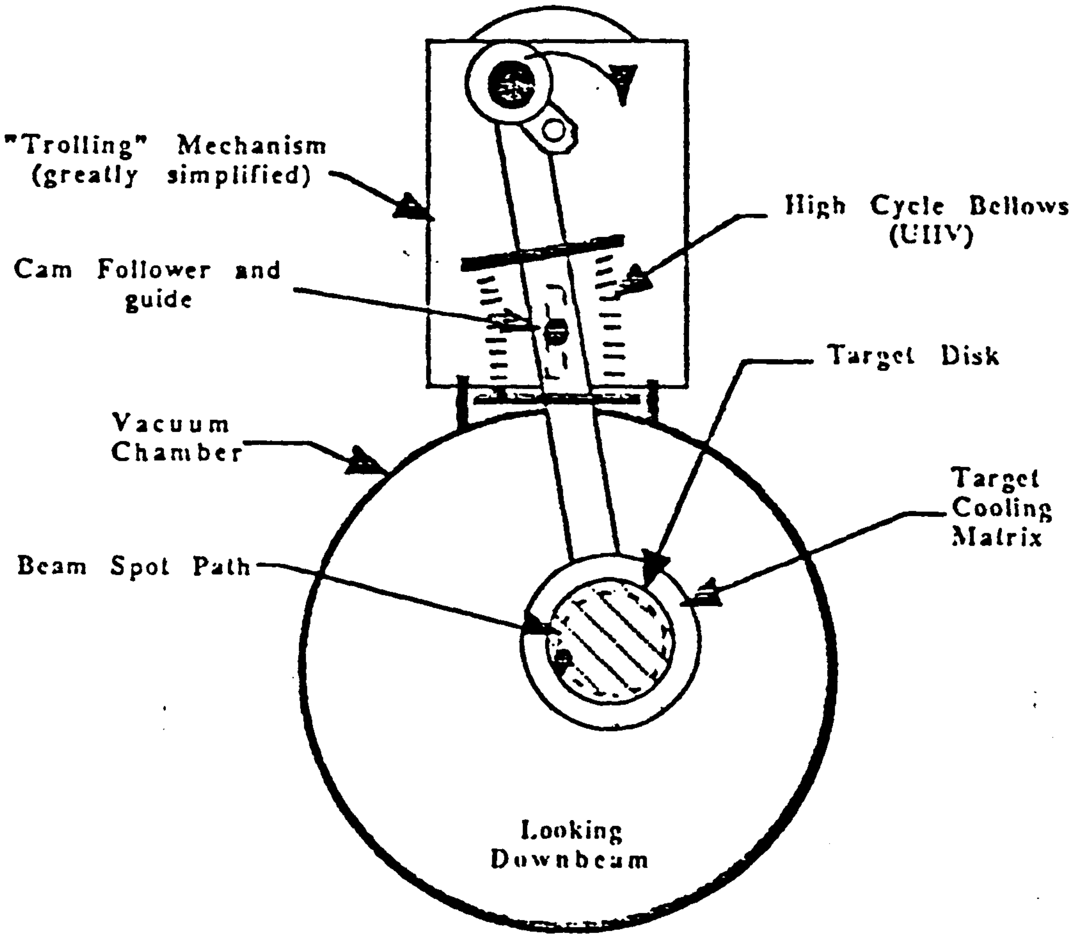
Fig. 3

Fig. 4



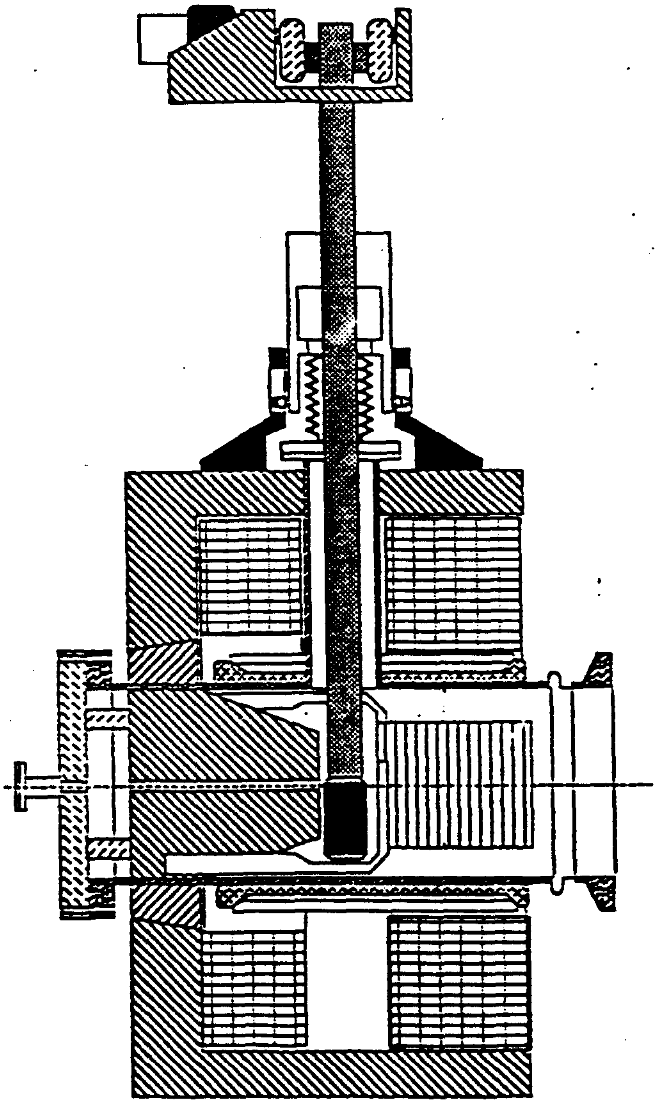
Minimum Distances [IN]
1-3 = 0.499
2-4 = 0.500
1-2 = 0.164
2-3 = 0.163
3-4 = 0.164
4-1 = 0.162
1
2
3
4
- Nominal Profile
- Tolerance +-.0005 in.
- Deviations
Leitz
QUINDOS
SLC QUAD. LAMINATION
PF-220-003-01-R0
14-AUG-90 10:02:02
BERND WAND

Fig. 5



"Trolling" Target Mechanism

Fig. 6



Complete Module Assembly

Fig. 7