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TITLE: **IRIS TILTING AND RF STEERING IN THE SLAC LINAC** *

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1. Introduction

For some time now, the sources of RF transverse beam steering in the SLAC Linac have been a mystery. The previously known sources, coupler asymmetries[1] and survey misalignment, have predicted deflections which are frequently much smaller than the observed deflections.[2] A new source of RF steering has been discovered: the tilting of accelerator irises. Measurements of iris tilting in a forty foot accelerator girder are compared with measurements of RF beam deflections[3] and are found to be strongly correlated.

2. RF Deflection From Tilted Irises

External mechanical measurements of the SLAC Linac have revealed that the cylinders of the accelerating structure sometimes exhibit tilting as shown in Fig. 1 and almost always have conical shapes as shown in Fig. 2. Conical distortions will not cause asymmetries in the electromagnetic fields, but tilted cylinders and the resulting tilted irises will produce asymmetries and RF beam deflections.

Mechanical measurements were made on many accelerator sections to determine the shape of the cylinders. The measurements were taken using a depth micrometer. The tilt of each cylinder was determined by measuring the depth of the upstream and downstream surfaces relative to a plane defined by neighboring irises and cylinders. Measurements on all four quadrants of a cylinder allowed the determination of the tilt and cone angles in both planes. Examples of vertical position measurements from a ten foot accelerator section (Girder 2-4a) are shown in Table I. Due to mechanical interferences, only about one half the cells could be measured. On this section the bottom surfaces slant much more than the top surfaces indicating tilted irises. Cells 34 through 52 are very tilted. An independent check of the mechanical measurements was made by the Precision

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Alignment Department using an optical level. The results are shown in Fig. 3. The elevation of eight cylinders and irises are shown. The irises (I) are reasonably aligned, but the upstream (U) and downstream(D) cylinder surfaces show marked tilts.

The tilt angle T and cone angle C, as defined in Figs. 1 and 2, have been measured for several ten foot accelerating sections, and a summary is shown in Table 2. All the sections show a non-zero cone angle, and many show large tilt angles. The spectra of measured tilt and cone angles are shown in Fig.4.

The origin of the cone angles is most likely the brazing process. The thermal gradients in the copper of the accelerator due to the rapidly moving ring brazer is probably the source. The coupler sections which were brazed slowly in a furnace do not have large cone angles. The tilting of the cylinders (and irises) most likely results from the fact that, although the transverse position of the cylinders and irises were held carefully during manufacturing, the rotations about a transverse axis were not well monitored. Thus, the rotations were determined by the tilts of the end couplers, small machining imperfections, or captured dirt particles. Many of the coupler assemblies on which accelerating structures were subsequently stacked had known measured tilts produced during their manufacture.

3. Predicting RF Deflections

A calculation of the effects of tilted irises on the electromagnetic fields in an accelerating structure has not yet been performed. Therefore, we will assume here that the fields rotate with the same angle as the nearby irises. The expected transverse deflection δp given to the beam can be calculated from the measured tilt angle T_i for each cell.

$$\delta p = \sum_{i=1}^{n} T_i \, \delta E_i \qquad [1]$$

where c is the speed of light, n is the number of cells, and δE_i is the energy gain in cell i.

The requirement of the SLC to keep the effect of RF fluctuations from significantly increasing the emittance of the accelerated beams is to keep the transverse RF deflections for a forty foot girder below 50 KeV/c. The typical girder (driven by one klystron) must provide about 250 MeV of energy to the beam. Therefore, from Eq. 1, the tilt angle must be kept below 0.21 milliradians to maintain the SLC specification. The requirement becomes less stringent for girders downstream in the Linac where the beam energy is higher. We see from Fig. 4 that several accelerator sections exceed the specification.

4. Comparison of Tilt Angles and Waveguide Deflections of Girder 2-4

The predicted waveguide deflections of Girder 2-4 from mechanical effects are compared with measured RF beam deflections in the vertical plane. The deflections are characterized by two deflection angles or kicks placed at the one quarter and three quarter positions within the girder. See Fig. 5. The sources of possible RF beam deflections are coupler asymmetries, survey errors and tilted irises. Coupler asymmetries associated with the RF feeds exist only in the horizontal plane, so no vertical deflection is expected. The Girder 2-4 was aligned in April of 1984, and the resulting external vertical survey, shown in Fig. 5, gives predictions of beam deflections which are quite small. On the other hand, the results of the tilted iris measurements in Table 2 predict large deflections. A summary of the predictions are shown in Table 3. Tilted irises dominate the predictions.

The RF beam deflections were measured[3] using the equipment shown in Fig. 5. The RF power to Girder 2-4 was turned on and off, and the resulting beam deflection was measured on two downstream beam position monitors (BPMO). The effective kicks at the one quarter and three quarter points within the girder were determined. The measured values are included in Table 3.

The observations in Table 3 show that there is a strong correlation between the measured RF deflections and those predicted from the mechanical tilt measurements. In order to make the correlation stronger, two improvements must be made:

1. More cells must be measured per accelerator section. This requires that a new measurement technique be developed.
2. A proper calculation of the field rotation with tilted irises must be performed using a three dimensional cavity computer code.

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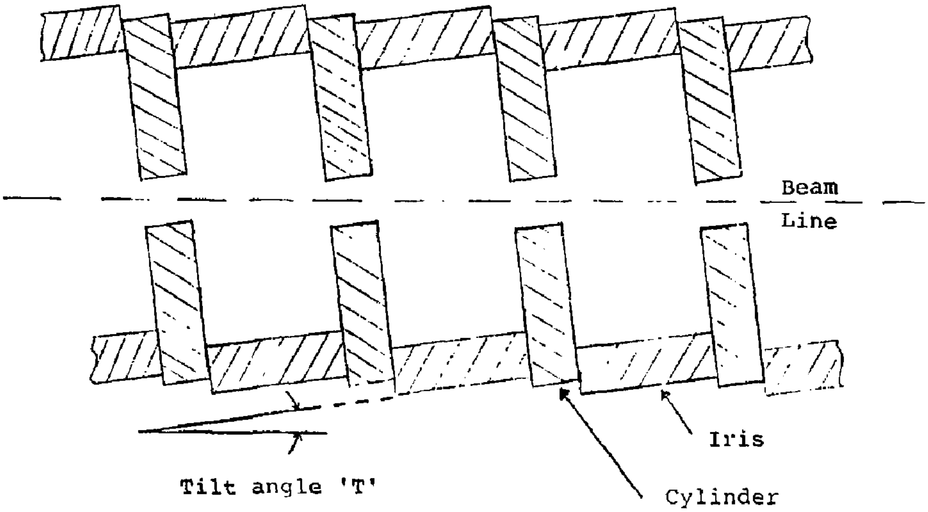

Fig. 1 SLAC diskloaded waveguide showing (exaggerated) observed tilts of the irises and cylinders.

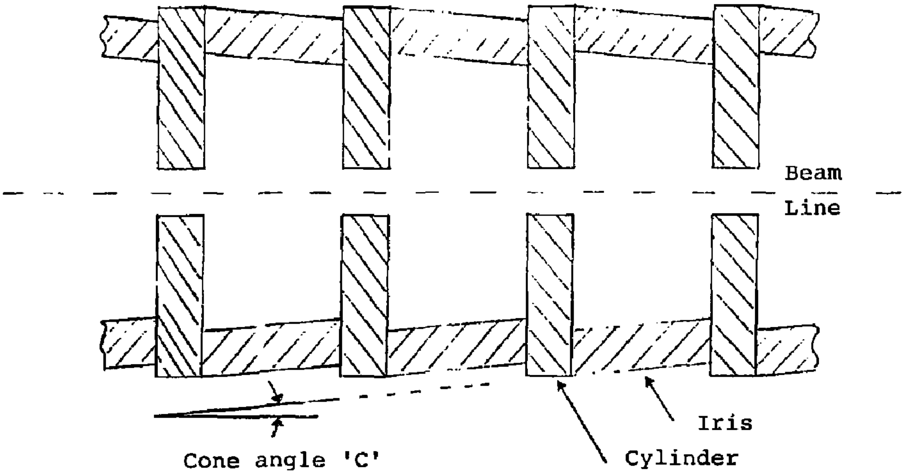

Fig. 2 SLAC diskloaded waveguide showing (exaggerated) the conical shape of the cylinders.

TABLE 1. Vertical external measurements of waveguide section 2-4a. Depth micrometer measurements were taken to determine the slope of the cylinders of the diskload waveguide. The blanks in the data are due to mechanical interferences. The symbol 'd' stands for tilting down and 'u' up. The units are thousandths of inches.

Girder # = 2-4 Section # = a Seeman

Date = 6/18/84

49 cells measured
Vertical Only

Cell #	Top	Bottom
1	–	–
2	–	–
3	0.2u	0.0
4	0.0	0.0
5	–	–
6	–	–
7	–	–
8	–	–
9	–	–
10	0.6d	1.3u
11	0.8d	1.2u
12	0.6d	1.2u
13	0.2d	1.1u
14	–	–
15	–	–
16	–	–
17	0.0	1.2u
18	0.7d	1.4u
19	0.0	1.7u
20	0.1d	0.6u
21	0.1d	1.0u
22	0.2d	1.4u
23	0.4d	1.6u
24	0.4d	1.6u
25	0.6d	1.7u
26	0.2d	1.7u
27	0.1d	1.7u
28	–	–
29	–	–
30	–	–
31	–	–
32	–	–
33	–	–
34	0.2d	2.0u
35	0.4d	1.7u
36	0.1u	1.0u
37	0.0	1.3u
38	0.0	2.0u
39	0.0	1.1u
40	0.0	1.4u
41	–	–
42	–	–
43	–	–
44	–	–
Σ =	5.3×10^{-3} inches	30.9×10^{-3} inches

Cell #	Top	Bottom
45	–	–
46	0.2d	2.2u
47	0.2d	1.8u
48	0.2d	0.9u
49	0.2d	2.5u
50	0.2d	2.7u
51	0.2d	2.0u
52	0.4d	1.5u
53	–	–
54	–	–
55	–	–
56	–	–
57	–	–
58	–	–
59	–	–
60	0.3d	1.0u
61	0.3d	1.0u
62	0.3d	1.0u
63	0.1d	1.1u
64	0.0	1.2u
65	0.2d	1.0u
66	0.7d	1.1u
67	0.1d	1.2u
68	0.2d	0.9u
69	0.1d	0.8u
70	0.2d	1.4u
71	0.1d	1.7u
72	0.6d	1.5u
73	0.0	1.2u
74	0.6d	1.8u
75	–	–
76	–	–
77	0.3d	1.7u
78	–	–
79	–	–
80	–	–
81	–	–
82	0.0	0.0
83	0.2d	0.0
84	–	–
85	–	–
86	–	–
87	–	–
88	–	–
Σ =	5.9×10^{-3} inches	33.2×10^{-3} inches

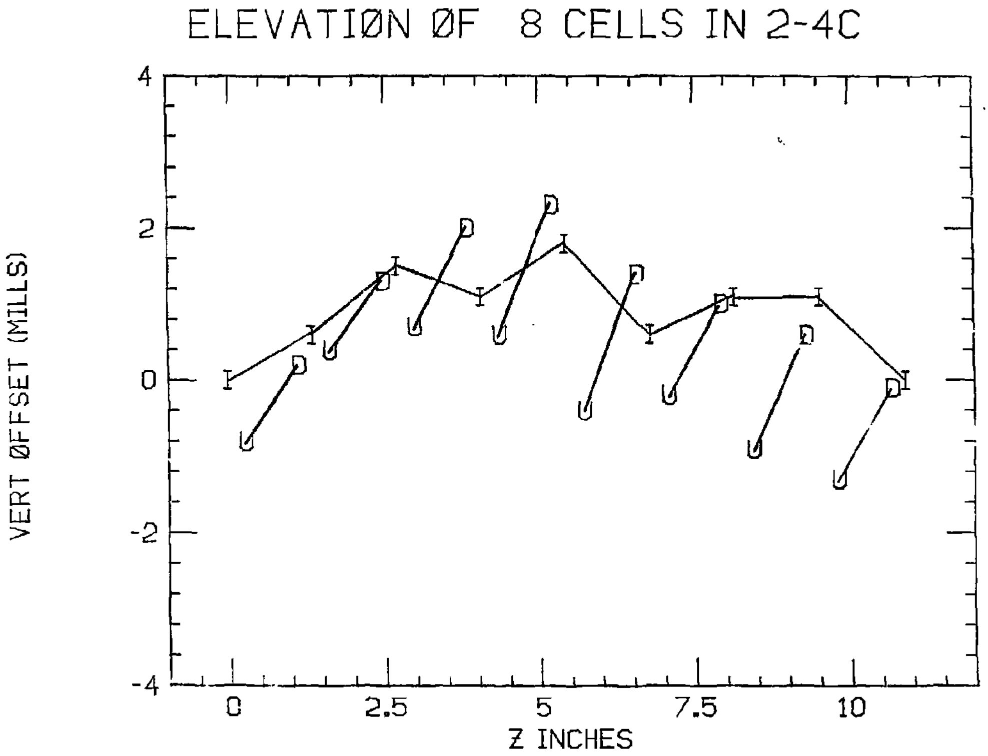

FIG. 3. Observations of tilted disks using an optical level. The irises (I) are relatively flat here. However, the cylinders have a decided upstream (U) to downstream (D) tilt.

TABLE 2. Measurements of the cone and tilt angles for nine waveguide sections. N is the number of cells measured per waveguide. All sections have a non-zero cone angle, the mean is 0.6 ± 0.2 mrad. The mean of the tilt angle for all sections is near zero, but individual values as high as 0.7 mrad were observed.

Section	Vertical			Horizontal		
	C ($\times 10^3$)	T ($\times 10^3$)	N	C ($\times 10^3$)	T ($\times 10^3$)	N
2-4a	0.65 ± .04	0.42 ± .04	38	1.09 ± .07	0.71 ± .07	13
2-4b	0.57 ± .05	0.24 ± .05	27	0.35 ± .06	−.06 ± .06	19
2-4c	0.45 ± .06	−0.43 ± .06	16	0.41 ± .06	0.51 ± .06	16
2-4d	0.51 ± .06	0.14 ± .06	16	0.67 ± .06	−0.45 ± .06	16
2-5b	0.89 ± .06	−.04 ± .06	16	0.91 ± .06	0.07 ± .06	16
2-5d	0.50 ± .06	−0.64 ± .06	16	0.38 ± .06	0.50 ± .06	16
8-2b	0.37 ± .08	−.01 ± .08	10	0.64 ± .08	0.00 ± .08	10
8-2c	0.41 ± .08	−.29 ± .08	11	0.31 ± .08	0.16 ± .08	11
8-2d	0.06 ± .11	−.40 ± .11	5	0.06 ± .11	−0.06 ± .11	5

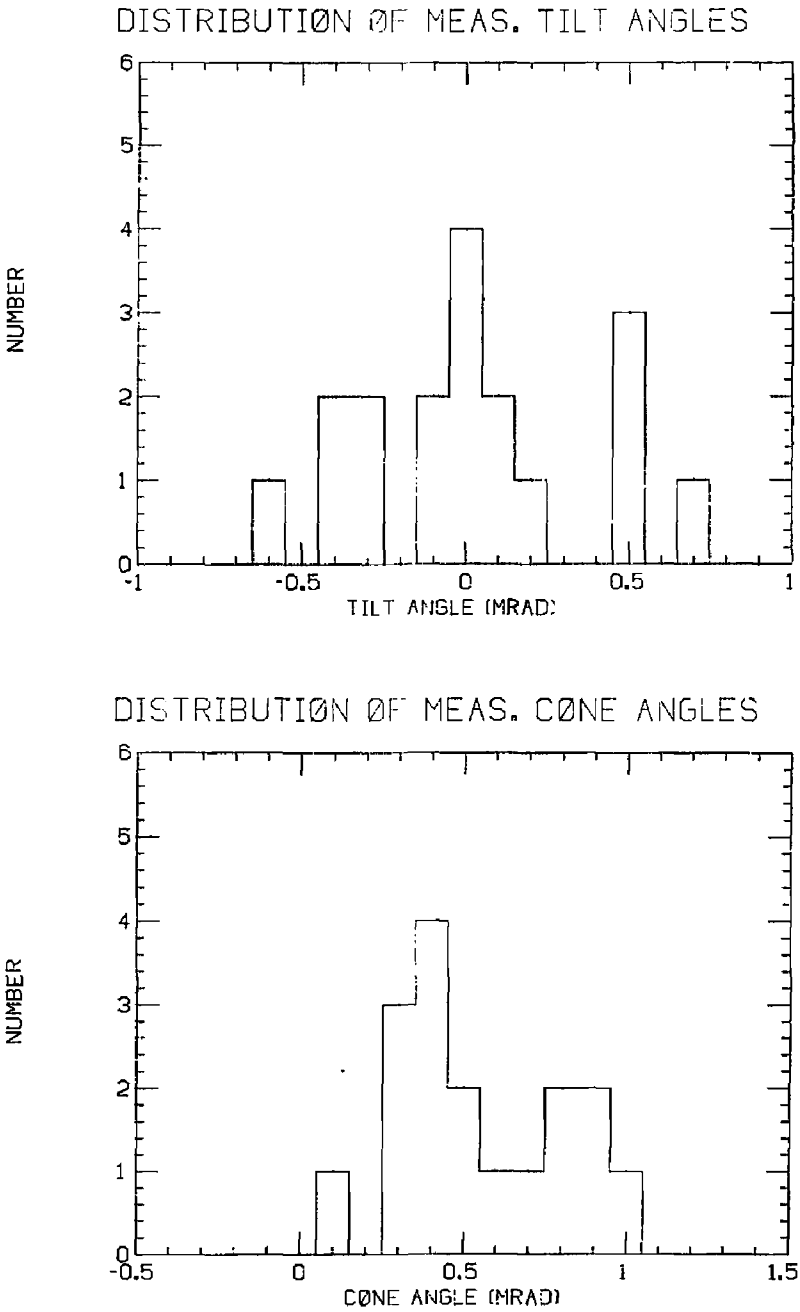

FIG. 4. Spectra of measured tilt and cone angles of several SLAC ten-foot linac accelerating structures.

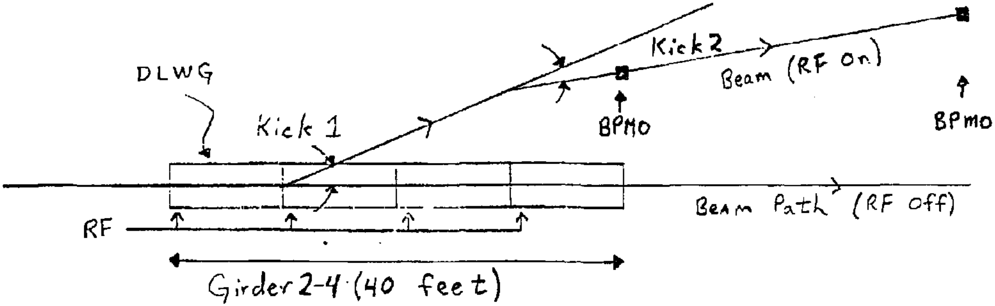

FIG. 5. The waveguide kicks were measured by exciting the RF power to a girder and measuring the deflection of the beam on two downstream beam position monitors (BPMO). The effective kick of the girder can be characterized by a pair of kicks located at the one quarter and three quarters points in the girder.

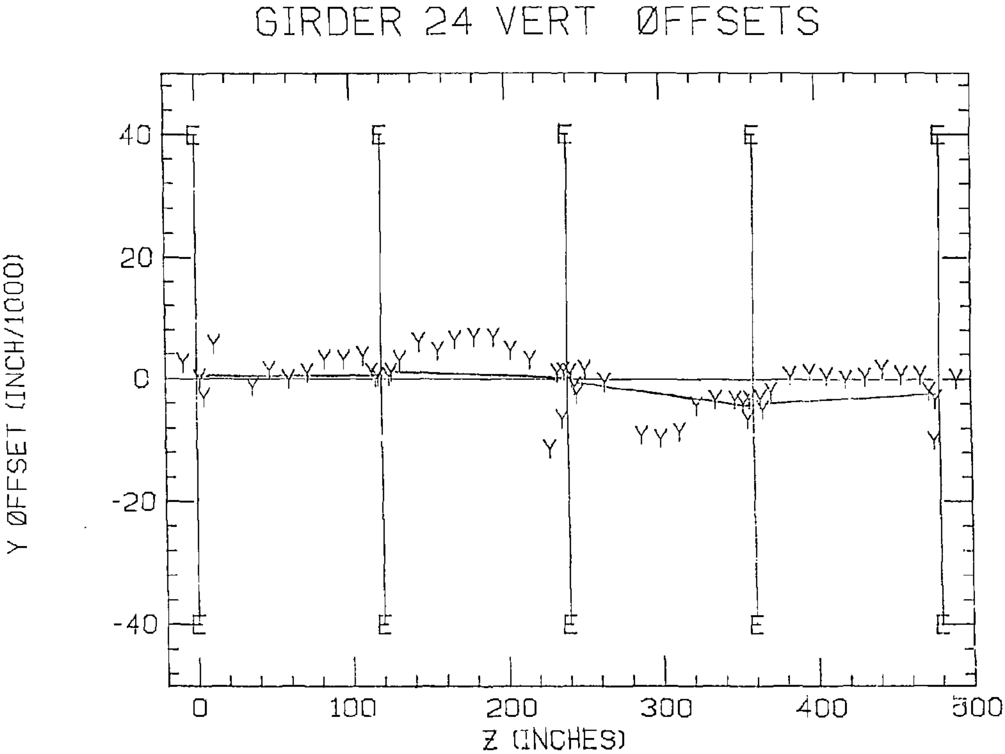

FIG. 6. Vertical external survey of irises on the top of girder 2-4 after straightening in April 1984.

TABLE 3: MEASURED AND PREDICTED ACCELERATING CAVITY RF BEAM DEFLECTIONS OF GIRDER 2-4. THE MEASUREMENTS WERE TAKEN IN THE VERTICAL PLANE WITHOUT SLED AT 28 MW.

MEASURED AND PREDICTED WAVEGUIDE KICKS OF GIRDER 2-4

(Vertical Plane)

PREDICTIONS/MEASUREMENTS	KICK 1	KICK 2
Coupler Asymmetry	0.0 kev/c	0.0 kev/c
Survey Errors	0.2 kev/c	-0.2 kev/c
Tilted Disks	17.2 kev/c	-6.0 kev/c
Total Predicted	17.4 kev/c	-6.2 kev/c
Measured Kicks	29.2 kev/c	-3.7 kev/c