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The U Line--1981

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Collider Accelerator Department

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AGS Division Technical Note
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Introduction

This technical note is an attempt to redocument the FEB transport line as beam sizes observed on "U" line flags do not compare well with the calculated beam sizes. Magnet locations were checked and compared with the locations in the FEB manual. Flags were removed and measured. In most cases new flags were reinstalled. Power supply and magnet information was obtained from the EAG magnetics section and compared with observed magnetic information. The beam pipe size was measured along the U line. The effects of the correction sextupole being at the wrong polarity and UQ8A being run at a very high current were studied.

Magnet and Power Supply Data

Figure 1a - 1e shows a printed output from the program QTUNE which lists the characteristics of the U line. A drawing of the beam line is shown in Figure 8. The magnet steel lengths were all measured. The effective lengths were obtained from the magnetics group or estimated. The magnet spacings were measured when possible and compared with the FEB manual. The trim magnets and new magnets were located. No major discrepancies were found between the FEB manual and the "U" line. Figure 1a-b shows the magnet effective lengths, locations, types and apertures. The flag locations are given. The power supply information is shown with the maximum power supply current. Figure 1c repeats some information in 1a - 1b and also gives the magnetic field data. This data is expressed as a power series and is valid for all currents from zero to the maximum magnet current listed. The quadrupole gradient data was obtained from excitation curves and the effective length. The dipole KG-IN information was obtained in a similar manner.

For example, a quad gradient is:

$$G = A_\emptyset + A_1 I + A_2 I^2 + A_3 I^3 + A_4 I^4 \quad \text{kG/in}$$

with the current in kiloamps. The power series represents the data supplied within ± 0.4% in most cases and ± 2% in the worst case.

Figure 1d - 1e shows calculated information assuming the power supplies are at a given AGAST setting. The settings listed are also used for the groups of Figures 3 and 6. A negative command or readback corresponds to an AGAST "A" reading--213A is -213. The current and field information is calculated from the constants of Figure 1a - 1c. As the note in Figure 1e explains, the gain of the elements (GEL) is the bend angle of the dipoles or the gradient of the quads with the proper sign for a horizontal or vertical focusing quad. On Figure 1e, certain useful variables available on AGAST and calculated by the QTUNE program are defined. All AGAST names having a "%" character are parameters calculated by the program. Further information can be found on a paper on the "QTUNE" program.

Figure 1f shows the location and power supply information for the "U" line trim magnets. The trim magnet information is not used to calculate beam sizes. All dipole or pitching trim magnets in the "U" line are 6.75D25 magnets. The constants for this magnet are:

$A_\emptyset$ = 0.09519696 Eff. length = 30.75 inch

A_1 = 103.4235 Max. magnet current = 0.60 kA

A_2 = -22.57931

A_3 = 172.3323

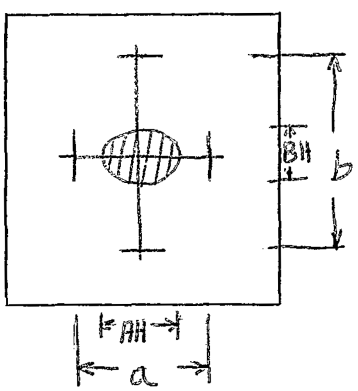
A_4 = -220.1772

$$\text{KG-In} = A_\emptyset + A_1 I + A_2 I^2 + A_3 I^3 \text{ for I in kiloamps.}$$

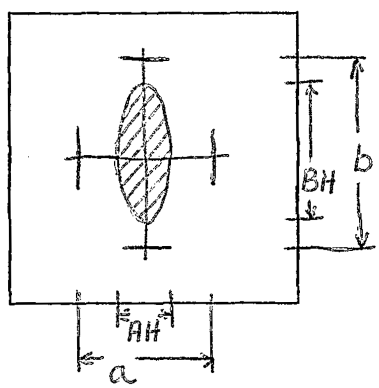
The power supplies were calibrated in June 1981 by Joe LeLaidier, an EAG technician. The magnetic fields were measured in most magnets later in June, but at a different AGAST setting from Figure 1 with the Bell Gaussmeter. The probe was held next to the pole tips by Ken Reece. Using the AGAST CMD or RDBK that gave the most accurate power supply calibration, the magnetic fields were calculated in the "U" line magnets. The results are shown in Figure 2 using measured pole tip radii. For the sextupole US1A, the gradient dimensions are KG/in^2. The pole tip fields for UQ12, 13 and 14 were not measured because magnet covers or tight spaces prevented putting the probe in the magnet gap. Figure 2 shows large errors for UQ7, UQ8A and the correction sextupoles US1A and US1B.

Beam sizes in the FEB line can now be measured only from flag measurements. The flags are radelin that are mounted at a 45 degree angle so that a TV monitor may observe the beam striking the flag. Except for U799F all flags are tilted in the vertical plane. Flag U799F is tilted in the horizontal plane. To compensate for the tilt, the graticule spacing in the tilt plan is 1.41 times the effective spacing as observed on the TV monitor. All "U" line flags have been measured and most have been replaced with new flags. One flag was found to be mounted incorrectly in July 1981, so that the long dimension was not in the tilt plane. In most cases, the graticules appear about one inch apart on the TV so that a beam just touching all four marks would be a one inch by one inch beam. Some flags have holes and one flag has a hole and no marks. The following table shows the flags now (October 1981) and as they were in May-June 1981 and perhaps for several years before 1981. The flag 273F is located at 273 feet but is labelled on the flag as 303. It was necessary to use the shorter 303 instrument box in the 273 location when the replacement sextupoles were used near the 8 degree magnets.

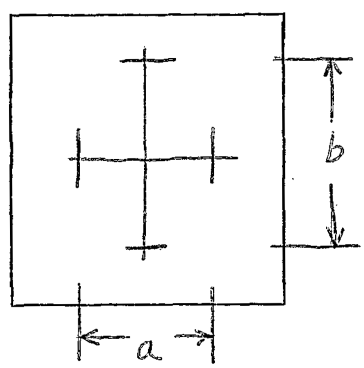
U15F, U380F



U165F, U273(303)



U618F, U667F, U772F, U799F



	OLD DIMENSIONS				CURRENT DIMENSIONS			
	Actual		On TV		Actual		On TV	
	a(AH)	b(BH)	a(AH)	b(BH)	a(AH)	b(BH)	a(AH)	b(BH)
U15F	2.0	1.25	2.0	0.88	2.0	1.25	2.0	0.88
Hole U15F	1.31	0.63	1.31	0.44	1.31	0.63	1.31	0.44
U380F	1.0	1.42	1.0	1.0	1.02	1.41	1.02	1.0
Hole U380F	1.38	0.4	1.38	0.28	1.31	0.37	1.38	0.26
U165F		NO GRATICULES				NO GRATICULES		
Hole U165F	0.75	1.0	0.75	0.70	0.75	1.0	0.75	0.70
U273(303)	0.78	1.51	0.78	1.07	0.7	1.5	0.7	1.06
Hole U273(303)	0.47	1.69	0.47	1.20	0.44	1.62	0.44	1.15

(All Dimensions in Inches)

	OLD DIMENSIONS				CURRENT DIMENSIONS (10/81)			
	Actual		On TV		Actual		On TV	
	a	b	a	b	a	b	a	b
U618F	1.4	1.0	1.4	0.7	1.0	1.38	1.0	0.98
U667F	1.02	1.35	1.02	0.96	1.0	1.25	1.0	0.88
U772F	1.0	1.38	1.0	0.98	1.0	1.38	1.0	0.98
U799F	1.37	1.0	0.97	1.0	1.38	1.0	0.98	1.0
U815F	NO GRATICULES - 0.625 DIA.				NO GRATICULES - 0.625 DIA.			

"U" Line Flag Dimensions

The best known input beam is used to calculate the beam widths in the U line. Weng's[1] input emittance for the new H5 extraction system is used with input momentum dispersion and input momentum spread in the horizontal plane. The emittances listed in the FEB manual, used by Weng, and used in the QTUNE program are listed on the next page.

H13 Input FEB Emittance

		FEB Manual		Weng		QTUNE
α_x	=	-5.67		-5.67		-5.67
β_x	=	5.746 cm/mrad	=	57.46 m/rad	=	2.62 in/mrad
ε_x	=	0.12 cm-mrad(0.0472 in-mrad)				
ε_x	=	---		1.5×10^{-6}m-rad(0.5906 in-mrad)	=	0.006412 in-mrad rms
Δ P/P	=	---		± 0.12%	=	± 0.12%
X_p	=	---		-2.96 m/ratio (-2.96 cm/%)	=	-1.165 in/%
X^1_p	=			-295 mrad/ratio (-2.95 mrad/%)	=	-2.95 mrad/%
α_y	=	0.987		0.987		0.987
β_y	=	3.7 m/rad	=	0.370 cm/mrad	=	0.1457 in/mrad
ε_y	=	0.186 cm-mrad(0.0732 in-mrad)				
ε_y	=			1.5×10^{-6} m-rad(0.0590 in-mrad)	=	0.006412 in-mrad rms

Weng used a slightly different horizontal emittance from the FEB manual since he also included momentum spread and dispersion. Some beam sizes were first calculated using TRANSPORT to check the QTUNE program. The results compare very accurately. The QTUNE program was used to plot graphs since this program takes the information directly from an AGAST display. For historical reasons QTUNE uses the inch system and the rms emittance and plots beam sizes and make calculations for a 99% beam. The program also plots the momentum dispersion parameters along the beam line.

$$\varepsilon \text{ (99\% beam)} = -2 \ln (0.01)\, \varepsilon_{rms} = 9.2103\, \varepsilon_{rms}$$

beam width (99% beam) = 3.0348 (beam width for rms beam).

Beam Size Results

The following discussion uses beam half sizes. Using the best known flag sizes, as measured by J.W. Glenn, the observed beam sizes were:

Flag	Horizontal (inch)	Vertical (inch)
U15	0.67	0.28
U165	?	0.70
U273	0.35	0.60
U380	1.0	0.60
U618	0.35	1.37
U667	0.28	1.15
U772	0.87	0.28
U799	0.25	0.60
U815	0.030	0.020

Figure 3a - 3c show the calculated beam sizes in the "U" line using the AGAST settings and field expansions of Figure 1. Printed below the curve on Figure 3a are the AGAST settings and the calculated parameters that are defined on Figure 1e. The observed beam sizes are marked as crosses. Figure 3a also shows the calculated value of the momentum dispersion parameters X_p and X'_p along the beam line. For clarity, these were left off Figures 3b and 3c. All curves are with the same AGAST settings of Figure 1. After the 8 degree magnet, the momentum dispersion parameters are:

$$X_p = 0.339 \text{ in/\%} \qquad X'_p = -2.04 \text{ mr/\%}$$

These parameters are U8%MD and U8%MP. For a dispersionless line after these magnets, these values should both be zero. Weng[1] shows that it is necessary to change the beam line upstream of the 8 degree magnets to achieve this since the "U" line has initial momentum dispersion.

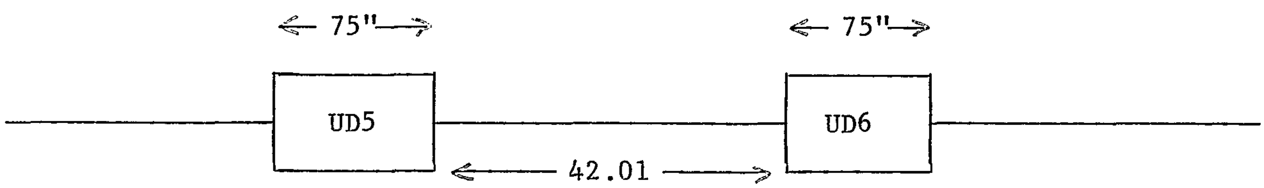
Figure 3 shows a large error between the calculated vertical half size and observed size in most of the beam line. The parameters TG%UH and TG%UV show that the calculated beam half sizes at the target are 0.256 and 0.076 inches which does not agree with the flag sizes. The cause for these errors is not known, but some possible causes were investigated.

Figure 4 and the following table show that small changes in UQ11-UQ14 will make the calculated beam small of the target. The small calculated beam of 52 by 25 mils is greater than the observed 30 by 20 mil beam.

Name	AGAST Start	AGAST Small Beam	Percent Change
UQ11	435B	514B	18.0
UQ12	2916A	2689A	- 7.8
UQ13	2746A	2511A	- 8.6
UQ14	1894B	1963B	3.6
Horiz. Half Size	0.257 inch	0.053 inch	
Vert. Half Size	0.076	0.025	

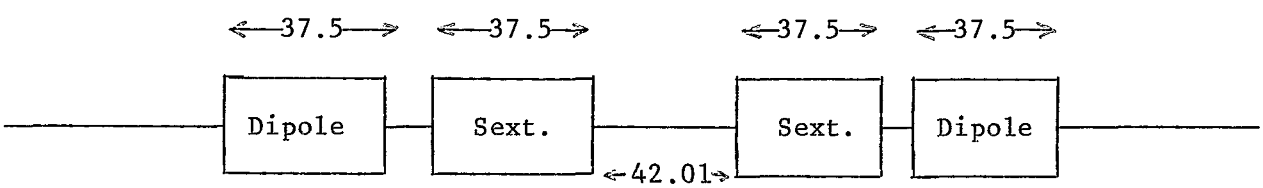
Sextupole Results

The effect of the correction sextupoles in the FEB line were investigated to try to explain the flag discrepancies. Second order TRANSPORT was used to determine sextupole effects. A simplification was made, as shown below, to separate the 8 degree dipole into a short dipole followed or preceeded by a short sextupole. Both short magnets had double the actual magnetic field.



Dipole = 2581.008 KG-in	2581.008 KG-in
Dipole = 34.413 KG	34.413 KG
Sextupole = 1.731 KG	1.731 KG
Sextupole = 0.4328 KG/in^2	0.4328 KG/in^2
Sextupole Radius = 2.0 inch	

Actual Physical System



Dipole = 68.82688 KG	Dipole = 68.8268 KG
Sextupole = 3.4622 KG	Sextupole = 3.4622 KG

System Used for Transport

The sextupole field in the 8 degree magnet is not well known. The following table gives the fields in that magnet and the external shimmed sextupole US1A.

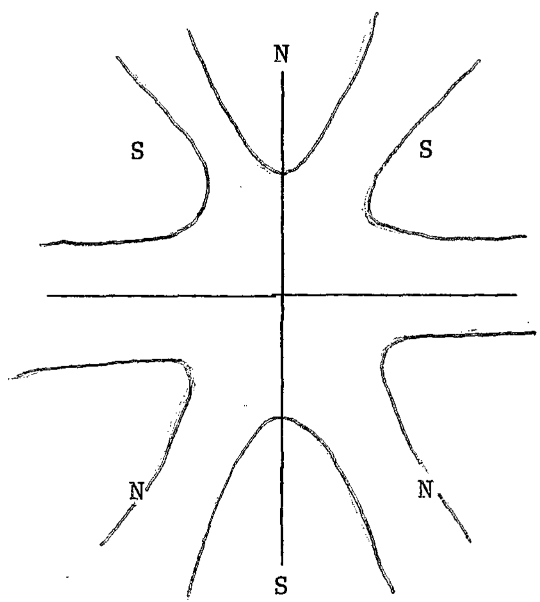
	8 Degree Correction Coil	External Shimmed Sextupole
$A_\emptyset$	= 0.00194	0.13574
A_1	= 2.317825	1.3395
A_2	= - 0.040949	0.66138
A_3	= - 0.35138	- 0.89414
A_4	= $\emptyset$	- 0.243625
Effective Length	= 75 inch	26.06 inch
Pole Tip Radius	= 2.0 inch	2.063 inch

Sextupole Gradient Sx Table

The gradient can be found from:

$$S_x = A_\emptyset + A_1 I + A_2 I^2 + A_3 I^3 + A_4 I^4 \text{ KG/in}^2 \text{ for I in kiloamps.}$$

The 8 degree dipoles produce a sextupole error field that adds to the dipole field on the horizontal midplane. Since the dipoles have a field that is up to bend protons to the east, the equivalent sextupole is as shown



Equivalent Sextupole Produced by the 8 Degree Dipoles

TRANSPORT considers this sextupole a negative sextupole. The external and internal correction sextupoles must have the opposite polarity.

Figures 5a - 5b give the TRANSPORT data file for the external sextupoles at the correct polarity to cancel the dipole error field. The results of several computer runs are shown in Figure 6 for the beam line starting at the first correction sextupole upstream of the 8 degree magnets. The power supplies are set at the same value as in Figure 2. Curve 1 is a first order calculation or a second order calculation, with no sextupoles which also is the same as Figures 3a - c. Curve 2 shows the effect of shorter dipoles at twice the field and no sextupoles. Curve 3 assumes that the correction sextupoles are off but the dipole error sextupoles are on. Curves 4 and 5 show the correction sextupoles on at the correct and wrong polarities. It should be noted that curves 3-5 are valid for either polarity of the dipole error field. Curve 4 shows that the correction sextupoles do cancel the effect of the error field. The only difference occurs down near Q11 in the horizontal plan and this difference is less than 0.030 inches. These correction sextupoles are also at a field 12 percent too strong to cancel the dipole error as shown below:

$$S_x \ \alpha \ \frac{\text{field}}{(\text{radius})^2} \times \text{length}$$

$$S_x = 32.46 \text{ KG/in for } 8^\circ \text{ error}$$

$$S_x = 36.34 \text{ KG/in for US1A}$$

The crosses show the measured beam sizes. It can be seen that if the correction sextupoles were at the wrong polarity, some vertical errors could be explained. However, the curves show that the horizontal beam would also blow up and this was not observed. One can conclude that the sextupoles were operating at the correct polarity.

Varying UQ8A

The quadrupole UQ8A is a vertical focusing quad that had a large error between calculated and measured gradients as shown in Figure 2. Figure 7 shows the effect of increasing the current in that magnet. For a current of 0.70 KA, the vertical beam fits inside the beam pipe and approaches the observed beam at 618F and 667F. This current, however, is 46 times the assumed current and larger than the maximum current from AGAST for 4000 counts (0.25 KA). This current is, however, less an the magnet rating of 1.2 kA. This effect is not understood, but another possible cause could be the excitation of spare magnets existing in the U line. For example, UQ8B is 28.8 feet downstream of UQ8A and cables are connected to the coils of this magnet.

Conclusions

The errors or discrepancies of Figure 3 have not been satisfactorily explained. Magnetic field measurements should be repeated. The unused magnets should be checked to confirm that they are not energized. If the beam line information can be verified, a new H13 emittance may be needed to produce a calculated beam similar to the observed beam.

References

1. W.T. Weng, Momentum Dispersion of AGS Fast Extracted Beam, BNL 24658, April 1978.
2. W.T. Weng, The New AGS Fast Extraction System, BNL 51310, September 1980.

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BFILE  (BEAM FILE NUMBER; 1=A,2=B,3=C,4=D,5=U)                              5
PBEAM  (BEAM MOMENTUM, GEV/C)                                           29.40
ABEF13 (ALPHA, BETA (KILOINCH), EPSILON (INCH-MRAD, RMS) AT F13
       HORIZONTAL:                               -6.6358    2.2680    0.0078
       VERTICAL:                                  0.8708    0.1279    0.0095
ABEH13 (ALPHA, BETA (KILOINCH), EPSILON (INCH-MRAD, RMS) AT H13
       HORIZONTAL:                               -5.6700    2.2620    0.0064
       VERTICAL:                                  0.9870    0.1457    0.0064
DPP    ((DELTA P/P) OR MOMEN.FRACT.IN % FOR 99%(U LN) BEAM)           0.1200
H13MOM (INPUT HORZ. MOMEN. DISPERSION AT H13; INCH/%,MR/%)
                     -1.1650 -2.9500
TEKVER (=1 FOR TEKTRONIX PLOTS,=2(MODEL 1200) OR -2(MODEL
             1100) VERSATEK & NO TUNING)                                    1
LFRAME (=0 OR NEG. TO SUPPRESS FRAMES & LABELS ON GRAPHS;
             -1,0 OR 1 FOR ALL GRAPHS; -2 OR 2 FOR NO MOMEN.
             DISPERSION PLOTS)                                              2
IAGSFG (AGS FLAG;=1 FOR MAGNET VALUES FROM TTY,=2 FOR
        AGAST RDBKS,=3 FOR AGAST COMMANDS)                                  3
PSTIME (POWER SUPPLY READ TIME IN MS AFTER TO)                           1100
ZRANGE (PLOTTING RANGE IN BEAM LINE FEET (MIN,MAX) )
                    0.000 (STARTING POINT OR 0 FEET FROM F13)
                10000.000 (END POINT OR END OF BEAM LINE)
IENUT (0="AGAST" OR TTY; -1 = OFFLINE "ENUTQ")                             -1
TEGFG (0=USE CURRENT "ENUTQ" "QTUNX.TEG" FILE;-1 TO
           CHANGE FILE NAME)                                                0
XYRANG (MAX. BEAM HALF SIZE FOR PLOTTING,INCH)                         1.0000

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RMS PARAMETERS:
ALPHA, BETA, EPSILON (H,V) AT H13: -5.6700  2.2620  0.0064  0.9870  0.1457  0.0064

UQ1  (-2727) UQ2  ( 3235) UD1-3( 2998) UD1-3( 2998) UD1-3( 2998) UQ3-6(-2845) UQ3-6(-2845) UQ3-6(-2845) UQ3-6(-2845) UQ7  ( 1727)
5-6( 3847) UD5-6( 3847) UQ8-9(-3534) UQ8A (  240) UQ8-9(-3534) UQ10 ( 1345) UQ11 (  435) UQ12 (-2916) UQ13 (-2746) UQ14 ( 1894)
 U8ZMD     U8ZMP     UTZHZ     UTZHX     UTZVZ     UTZVX     TGZUH     TGZUV
  339.76 -2040.37   -133.88     31.04     30.02     24.62    256.90     76.09

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                      "U" LINE MAGNETS FROM H13 TO U TARGET
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---ELEMENT-- #	NAME	LABEL	---MAGNET------ KIND	GROUP	#	Z(U/S) INCH	LENGTH INCH	XAPER INCH	YAPER INCH	POWER SUPPLY INFORMATION --PRIMARY DDF	AMPS/DCN	----MAX- KAMPS	-SECONDARY- DDF	AMPS/DCN
1			DRIFT		0	0.000	120.000	1.800	1.800					
2			DRIFT		0	120.000	72.320	1.440	1.440					
3		15F	DRIFT		0	192.320	0.001	0.000	0.000					
4			DRIFT		0	192.321	19.249	1.440	1.440					
5	UQ1	UQ1	QUAD	N3Q36	1	211.570	37.500	1.440	1.440	UQ1	0.7500	2.400		
6			DRIFT		0	249.070	19.500	1.440	1.440					
7	UQ2	UQ2	QUAD	N3Q36	1	268.570	37.500	1.440	1.440	UQ2	0.6250	2.300		
8			DRIFT		0	306.070	18.800	1.440	1.440					

Figure 1 a

9	UD1	UD1	RDPOL	4D78	11	324.870	81.900	1.940	1.440	UD1-3	1.0000	3.300
10			DRIFT		0	406.770	18.098	1.940	1.440			
11	UD2	UD2	RDPOL	4D78	11	424.868	81.900	1.940	1.440	UD1-3	1.0000	3.300
12			DRIFT		0	506.768	18.098	1.940	1.440			
13	UD3	UD3	RDPOL	4D78	11	524.866	81.900	1.940	1.940	UD1-3	1.0000	3.300
14			DRIFT		0	606.766	548.000	2.690	2.690			
15			DRIFT		0	1154.766	75.880	1.690	1.690			
16	UQ3	UQ3	QUAD	4Q26	16	1230.646	28.598	1.690	1.690	UQ3-6	0.0750	0.400
17			DRIFT		0	1259.244	40.000	1.690	1.690			
18			DRIFT		0	1299.244	232.960	2.490	2.490			
19	UQ4	UQ4	QUAD	4Q26	16	1532.204	28.598	1.690	1.690	UQ3-6	-0.0750	0.400
20			DRIFT		0	1560.802	200.000	2.490	2.490			
21			DRIFT		0	1760.802	72.960	1.690	1.690			
22	UQ5	UQ5	QUAD	4Q26	16	1833.762	28.598	1.690	1.690	UQ3-6	-0.0750	0.400
23			DRIFT		0	1862.360	111.500	2.490	2.490			
24		165F	DRIFT		0	1973.860	0.001	0.000	0.000			
25			DRIFT		0	1973.861	161.458	2.490	2.490			
26	UQ6	UQ6	QUAD	4Q26	16	2135.319	28.598	1.690	1.690	UQ3-6	0.0750	0.400
27			DRIFT		0	2163.917	272.960	2.490	2.490			
28	UQ7	UQ7	QUAD	4Q26	16	2436.877	28.598	1.690	1.690	UQ7	-0.~~0750~~ -0.100	0.300
29			DRIFT		0	2465.475	809.085	1.790	1.790			
30		273F	DRIFT		0	3274.560	0.001	0.000	0.000			
31			DRIFT		0	3274.561	95.499	1.790	1.790			
32	UD5	UD5	RDPOL	3SC72	19	3370.060	75.000	1.940	1.940	UD5-6	0.2500	1.000
33			DRIFT		0	3445.060	42.010	1.940	1.940			
34	UD6	UD6	RDPOL	3SC72	19	3487.070	75.000	1.940	1.940	UD5-6	0.2500	1.000
35			DRIFT		0	3562.070	115.630	1.940	1.940			
36	UQ8	UQ8	QUAD	4Q26	16	3677.700	28.598	1.690	1.690	UQ8-9	-0.0625	0.250
37			DRIFT		0	3706.298	68.000	1.940	1.940			
38			DRIFT		0	3774.298	121.950	3.690	3.690			
39	UQ8A	UQ8A	QUAD	8Q16P	17	3896.248	20.000	3.690	3.690	UQ8A	0.0625	0.250
40			DRIFT		0	3916.248	657.362	3.690	3.690			
41		380F	DRIFT		0	4573.610	0.001	0.000	0.000			
42			DRIFT		0	4573.611	95.449	3.690	3.690			
43	UQ9	UQ9	QUAD	4Q26	16	4669.060	28.598	1.690	1.690	UQ8-9	0.0625	0.250
44			DRIFT		0	4697.658	1081.260	1.690	1.690			
45	UQ10	UQ10	QUAD	4Q26	16	5778.918	28.598	1.690	1.690	UQ10	0.1000	0.388
46			DRIFT		0	5807.516	1608.484	1.690	1.690			
47		618F	DRIFT		0	7416.000	0.001	0.000	0.000			
48			DRIFT		0	7416.001	591.169	1.690	1.690			
49		667F	DRIFT		0	8007.170	0.001	0.000	0.000			
50			DRIFT		0	8007.171	84.200	1.690	1.690			
51	UQ11	UQ11	QUAD	4Q26	16	8091.371	28.598	1.690	1.690	UQ11	0.1000	0.115
52			DRIFT		0	8119.969	1155.302	1.690	1.690			
53		772F	DRIFT		0	9275.271	0.001	0.000	0.000			
54			DRIFT		0	9275.272	16.730	1.690	1.690			
55			DRIFT		0	9292.002	15.769	2.740	2.740			
56	UQ12	UQ12	QUAD	8Q32P	18	9307.771	36.000	2.740	2.740	UQ12	0.3750	1.200
57			DRIFT		0	9343.771	6.740	2.740	2.740			
58	UQ13	UQ13	QUAD	8Q32P	18	9350.511	36.000	2.740	2.740	UQ13	0.3750	1.200
59			DRIFT		0	9386.511	105.510	2.740	2.740			
60	UQ14	UQ14	QUAD	N3Q36	1	9492.021	37.500	1.440	1.440	UQ14	0.7500	2.400
61			DRIFT		0	9529.521	242.150	1.440	1.440			
62		815F	DRIFT		0	9771.671	0.001	0.000	0.000			
63			DRIFT		0	9771.672	11.000	1.440	1.440			
64		UTGT	DRIFT		0	9782.672	0.000	0.000	0.000			

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Figure 1 b

"U" LINE MAGNETS FROM H13 TO U TARGET

---ELEMENT--- *	NAME	LABEL	---MAGNET------ KIND	GROUP	*	EFF.LEN INCH	A0	KG/IN OR KG-IN POWER SERIES COEFFICIENTS FOR I IN KILOAMPS A1	A2	A3	A4	MAX.MAGNET KAMPS
1			DRIFT		0	120.000						
2			DRIFT		0	72.320						
3		15F	DRIFT		0	0.001						
4			DRIFT		0	19.249						
5	UQ1	UQ1	QUAD	N3Q36	1	37.500	1.5201630E-02	4.4772430E+00	1.9792940E-01	4.7379500E-02	-9.1596540E-02	2.600
6			DRIFT		0	19.500						
7	UQ2	UQ2	QUAD	N3Q36	1	37.500	1.5201630E-02	4.4772430E+00	1.9792940E-01	4.7379500E-02	-9.1596540E-02	2.600
8			DRIFT		0	18.800						
9	UD1	UD1	RDPOL	4D78	11	81.900	2.6068880E-01	3.2376880E+02	9.2981530E-01	-3.0072690E-01	0.0000000E+00	3.400
10			DRIFT		0	18.098						
11	UD2	UD2	RDPOL	4D78	11	81.900	2.6068880E-01	3.2376880E+02	9.2981530E-01	-3.0072690E-01	0.0000000E+00	3.400
12			DRIFT		0	18.098						
13	UD3	UD3	RDPOL	4D78	11	81.900	2.6068880E-01	3.2376880E+02	9.2981530E-01	-3.0072690E-01	0.0000000E+00	3.400
14			DRIFT		0	548.000						
15			DRIFT		0	75.880						
16	UQ3	UQ3	QUAD	4Q26	16	28.598	7.8877510E-03	9.2529370E+00	2.4783180E+00	-8.1294770E+00	-6.7577510E+00	0.550
17			DRIFT		0	40.000						
18			DRIFT		0	232.960						
19	UQ4	UQ4	QUAD	4Q26	16	28.598	7.8877510E-03	9.2529370E+00	2.4783180E+00	-8.1294770E+00	-6.7577510E+00	0.550
20			DRIFT		0	200.000						
21			DRIFT		0	72.960						
22	UQ5	UQ5	QUAD	4Q26	16	28.598	7.8877510E-03	9.2529370E+00	2.4783180E+00	-8.1294770E+00	-6.7577510E+00	0.550
23			DRIFT		0	111.500						
24		165F	DRIFT		0	0.001						
25			DRIFT		0	161.458						
26	UQ6	UQ6	QUAD	4Q26	16	28.598	7.8877510E-03	9.2529370E+00	2.4783180E+00	-8.1294770E+00	-6.7577510E+00	0.550
27			DRIFT		0	272.960						
28	UQ7	UQ7	QUAD	4Q26	16	28.598	7.8877510E-03	9.2529370E+00	2.4783180E+00	-8.1294770E+00	-6.7577510E+00	0.550
29			DRIFT		0	809.085						
30		273F	DRIFT		0	0.001						
31			DRIFT		0	95.499						
32	UD5	UD5	RDPOL	3SC72	19	75.000	-9.1349790E+00	3.2169220E+03	-3.5253800E+01	-5.2960020E+02	0.0000000E+00	1.100
33			DRIFT		0	42.010						
34	UD6	UD6	RDPOL	3SC72	19	75.000	-9.1349790E+00	3.2169220E+03	-3.5253800E+01	-5.2960020E+02	0.0000000E+00	1.100
35			DRIFT		0	115.630						
36	UQ8	UQ8	QUAD	4Q26	16	28.598	7.8877510E-03	9.2529370E+00	2.4783180E+00	-8.1294770E+00	-6.7577510E+00	0.550
37			DRIFT		0	68.000						
38			DRIFT		0	121.950						
39	UQ8A	UQ8A	QUAD	8Q16P	17	20.000	-1.2346600E-03	2.5374830E+00	-1.5826770E-01	1.0157320E-01	0.0000000E+00	1.200
40			DRIFT		0	657.362						
41		380F	DRIFT		0	0.001						
42			DRIFT		0	95.449						
43	UQ9	UQ9	QUAD	4Q26	16	28.598	7.8877510E-03	9.2529370E+00	2.4783180E+00	-8.1294770E+00	-6.7577510E+00	0.550
44			DRIFT		0	1081.260						
45	UQ10	UQ10	QUAD	4Q26	16	28.598	7.8877510E-03	9.2529370E+00	2.4783180E+00	-8.1294770E+00	-6.7577510E+00	0.550
46			DRIFT		0	1608.484						
47		618F	DRIFT		0	0.001						
48			DRIFT		0	591.169						
49		667F	DRIFT		0	0.001						
50			DRIFT		0	84.200						
51	UQ11	UQ11	QUAD	4Q26	16	28.598	7.8877510E-03	9.2529370E+00	2.4783180E+00	-8.1294770E+00	-6.7577510E+00	0.550
52			DRIFT		0	1155.302						
53		772F	DRIFT		0	0.001						
54			DRIFT		0	16.730						

Figure 1 c

55			DRIFT		0	15.769					
56	UQ12	UQ12	QUAD	8Q32P	18	36.000	-1.2346600E-03	2.5374830E+00	-1.5826770E-01	1.0157320E-01	0.0000000E+00	1.200
57			DRIFT		0	6.740					
58	UQ13	UQ13	QUAD	8Q32P	18	36.000	-1.2346600E-03	2.5374830E+00	-1.5826770E-01	1.0157320E-01	0.0000000E+00	1.200
59			DRIFT		0	105.510					
60	UQ14	UQ14	QUAD	N3Q36	1	37.500	1.5201630E-02	4.4772430E+00	1.9792940E-01	4.7379500E-02	-9.1596540E-02	2.600
61			DRIFT		0	242.150					
62		815F	DRIFT		0	0.001					
63			DRIFT		0	11.000					
64		UTGT	DRIFT		0	0.000					

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"U" LINE MAGNETS FROM H13 TO U TARGET

---ELEMENT---			MAGNET	---POWER SUPPLY DATA---				--MAGNET DATA FOR 29.400 GEV/C--		
#	NAME	LABEL	KIND	DDF1	CMD/RDBK	DDF2	CMD/RDBK	CURRENT(KA)	KG-IN OR KG/IN	GAIN(GEL)
1			DRIFT							0.0
2			DRIFT							0.0
3		15F	DRIFT							0.0
4			DRIFT							0.0
5	UQ1	UQ1	QUAD	UQ1	-2727		0	2.04525	-8.8028	-8.80283
6			DRIFT							0.0
7	UQ2	UQ2	QUAD	UQ2	3235		0	2.02187	8.7376	8.73765
8			DRIFT							0.0
9	UD1	UD1	RDPOL	UD1-3	2998		0	2.99800	971.1733	1.44121
10			DRIFT							0.0
11	UD2	UD2	RDPOL	UD1-3	2998		0	2.99800	971.1733	1.44121
12			DRIFT							0.0
13	UD3	UD3	RDPOL	UD1-3	2998		0	2.99800	971.1733	1.44121
14			DRIFT							0.0
15			DRIFT							0.0
16	UQ3	UQ3	QUAD	UQ3-6	-2845		0	0.21338	-2.0021	-2.00208
17			DRIFT							0.0
18			DRIFT							0.0
19	UQ4	UQ4	QUAD	UQ3-6	-2845		0	0.21338	2.0021	2.00208
20			DRIFT							0.0
21			DRIFT							0.0
22	UQ5	UQ5	QUAD	UQ3-6	-2845		0	0.21338	2.0021	2.00208
23			DRIFT							0.0
24		165F	DRIFT							0.0
25			DRIFT							0.0
26	UQ6	UQ6	QUAD	UQ3-6	-2845		0	0.21338	-2.0021	-2.00208
27			DRIFT							0.0
28	UQ7	UQ7	QUAD	UQ7	1727		0	0.12953	-1.2284	-1.22839
29			DRIFT							0.0
30		273F	DRIFT							0.0
31			DRIFT							0.0
32	UD5	UD5	RDPOL	UD5-6	3847		0	0.96175	2581.0078	3.83019
33			DRIFT							0.0
34	UD6	UD6	RDPOL	UD5-6	3847		0	0.96175	2581.0078	3.83019
35			DRIFT							0.0
36	UQ8	UQ8	QUAD	UQ8-9	-3534		0	0.22088	2.0689	2.06885
37			DRIFT							0.0
38			DRIFT							0.0
39	UQ8A	UQ8A	QUAD	UQ8A	240		0	0.01500	0.0368	0.03679
40			DRIFT							0.0

Figure 1 d

41		380F	DRIFT						0.0
42			DRIFT						0.0
43	UQ9	UQ9	QUAD	UQ8-9	-3534	0	0.22088	-2.0689	-2.06885
44			DRIFT						0.0
45	UQ10	UQ10	QUAD	UQ10	1345	0	0.13450	1.2752	1.27525
46			DRIFT						0.0
47		618F	DRIFT						0.0
48			DRIFT						0.0
49		667F	DRIFT						0.0
50			DRIFT						0.0
51	UQ11	UQ11	QUAD	UQ11	435	0	0.04350	0.4144	0.41439
52			DRIFT						0.0
53		772F	DRIFT						0.0
54			DRIFT						0.0
55			DRIFT						0.0
56	UQ12	UQ12	QUAD	UQ12	-2916	0	1.09350	-2.7171	-2.71707
57			DRIFT						0.0
58	UQ13	UQ13	QUAD	UQ13	-2746	0	1.02975	-2.5548	-2.55482
59			DRIFT						0.0
60	UQ14	UQ14	QUAD	UQ14	1894	0	1.42050	6.5374	6.53737
61			DRIFT						0.0
62		815F	DRIFT						0.0
63			DRIFT						0.0
64		UTGT	DRIFT						0.0

NOTE *****

A) CMD/RDBK -- READINGS ARE FROM ENUTQ PGM ; THE "A" RDBK IS NEGATIVE -- IE. 2140A = -2140.
B) DDF2 (SECONDARY P.S. READBACKS) ARE NOT SA3 RDBKS BUT READINGS OF TRIM P.S.
C) KGIN -- KG/IN FOR QUADS; KG-IN FOR DIPOLES & ONLY APPROX. FOR DIPOLES WITH TRIM SUPPLIES.
D) GEL -- = 0 FOR DRIFT; -KG/IN FOR H.F. QUAD; +KG/IN FOR V.F. QUAD; BEND ANGLE (DEGREES) FOR DIPOLES (+ = EAST).

NAME(??Z??)AREA(FEB)COMP(   )DEVTP(   )ADDR(   ) WHO(   )WHR(   )22-OCT-81

	EQUIP	AREA	DEVICE TYPE	DEFINITION
1	TGZUH	FEB	(REFERENCE)	(CALCULATED HORZ. HALF WIDTH BEAM SIZE IN MILS AT U TGT. - QTUNE PGM)
2	TGZUV	FEB	(REFERENCE)	(CALCULATED VERT. HALF WIDTH BEAM SIZE IN MILS AT U TGT. - QTUNE PGM)
3	U8ZMD	FEB	(REFERENCE)	(1000 X CALC. MOMENT. DISPERSION(INCH/RATIO) AT END OF 8 DEG. MAGNET.)
4	U8ZMP	FEB	(REFERENCE)	(1000 X CALC. MOMENT. DISPERSION PRIME(MR/RATIO) AT END OF 8 DEG. MAG)
5	UTZHX	FEB	(REFERENCE)	(HALF WIDTH(MILS) OF HORZ. BEAM AT WAIST NEAR TGT. - QTUNE PGM. USES)
6	UTZHZ	FEB	(REFERENCE)	(Z POS. OF U TGT. HORZ. WAIST, INCH; 0=U TGT.; -50=50 IN. UPSTRM U TG)
7	UTZVX	FEB	(REFERENCE)	(HALF WIDTH(MILS) OF VERT. BEAM AT WAIST NEAR TGT. - QTUNE PGM. USES)
8	UTZVZ	FEB	(REFERENCE)	(Z POS. OF U TGT. VERT. WAIST, INCH; 0=U TGT.; -50=50 IN. UPSTRM U TG)

Figure 1 e

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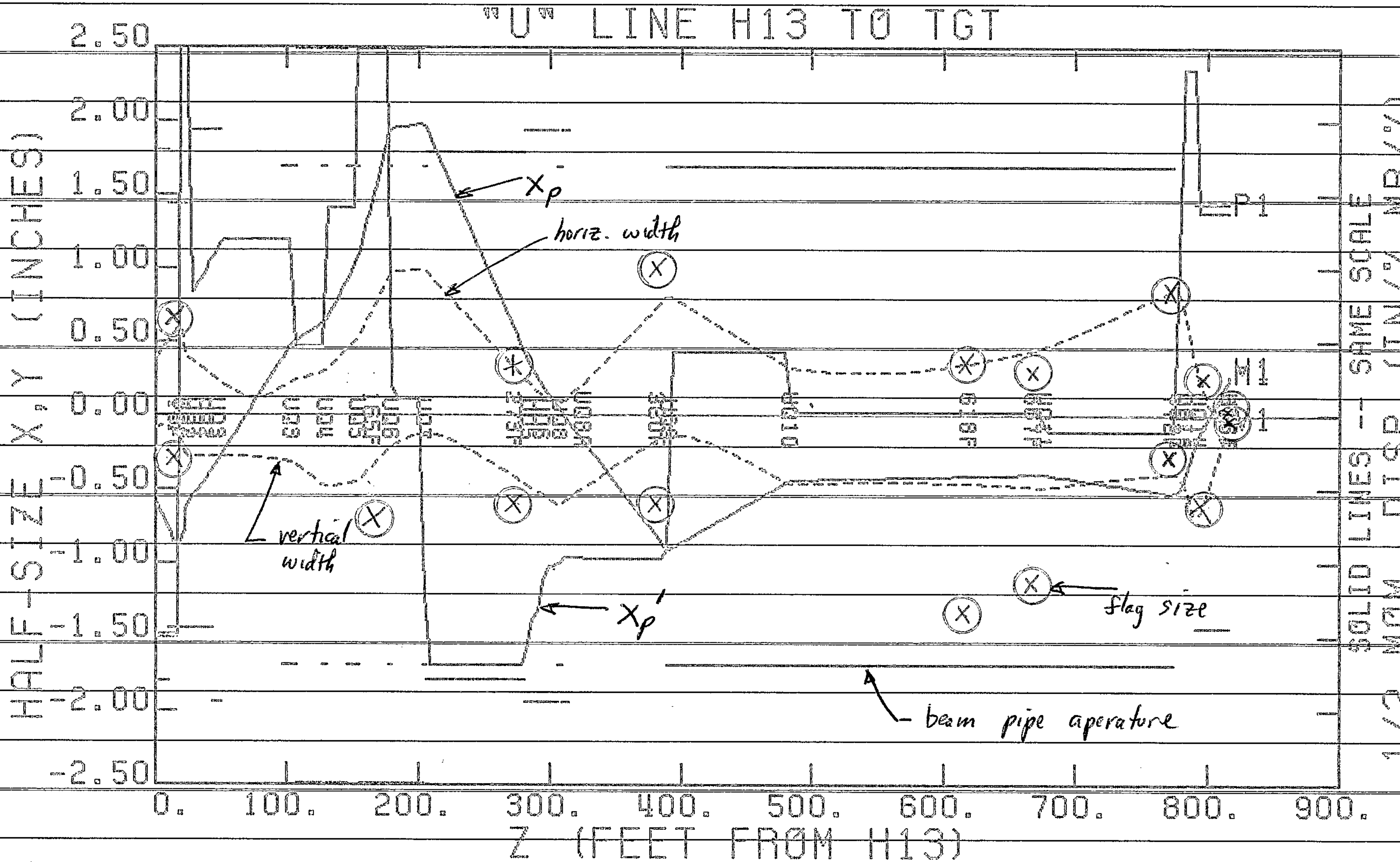
"U" LINE TRIM MAGNETS FROM H13 TO U TARGET

---ELEMENT-- #	NAME	LABEL	---MAGNET------ KIND	GROUP	#	Z(U/S) INCH	LENGTH INCH	XAPER INCH	YAPER INCH	POWER SUPPLY INFORMATION --PRIMARY----- DDF	AMPS/DCN	-MAX- KAMPS	-SECONDARY- DDF	AMPS/DCN
2A			DRIFT			0.00	95.945							
2B	UP1		WDPOL	6.75D24		95.945	30.75			UP1	0.10	0.388		
2C			DRIFT			126.695	84.875							
5	UQ1		QUAD	N3Q36		211.57	37.5			UQ1	0.75	2.4		
5A			DRIFT			249.07								
16	UQ3		QUAD	4Q26		1230.646	28.6			UQ3-6	0.0750	0.400		
17A			DRIFT			1259.246	9.575							
17B	UP2		WDPOL	6.75D24		1268.821	30.75			UP2	0.10	0.388		
17C			DRIFT			1299.571	232.633							
19	UQ4		QUAD	4Q26		1532.204	28.6			UQ3-6	-0.0750	0.400		
20A			DRIFT			1560.804	218.635							
20B	UD4		WDPOL	6.75D24		1779.439	30.75			UD4	0.10	0.388		
20C			DRIFT			1810.189	23.573							
22	UQ5		QUAD	4Q26		1833.762	28.6			UQ3-6	-0.0750	0.400		
36	UQ8		QUAD	4Q26		3677.70	28.6			UQ8-9	-0.0625	0.250		
37A			DRIFT			3706.30	21.575							
37B	UP3		WDPOL	6.75D24		3727.875	30.75			UP3	0.10	0.388		
37C			DRIFT			3758.625	137.623							
39	UQ8A		QUAD	8Q16P		3896.248	20.0			UQ8A	0.0625	0.250		
40A			DRIFT			3916.248	346.0							
40B	UQ8B		QUAD	8Q16P		4262.248	20.0							
40C			DRIFT			4282.248	386.812							
43	UQ9		QUAD	4Q26		4669.060	28.6			UQ8-9	0.0625	0.250		
44A			DRIFT			4697.66	118.578							
44B	UD4A		WDPOL	6.75D24		4816.238	30.75			UD4A	0.10	0.388		
44C			DRIFT			4846.988	931.930							
45	UQ10		QUAD	4Q26		5778.918	28.6			UQ10	0.1000	0.388		
58	UQ13		QUAD	8Q32P		9350.511	36.0			UQ13	0.3750	1.200		
59A			DRIFT			9386.511	22.418							
59B	UD7		WDPOL	6.75D24		9408.929	30.75			UD7	0.100	0.388		
59C			DRIFT			9439.679	-.745							
59D	UP4		WDPOL	6.75D24		9438.934	30.75			UP4	0.100	0.388		
59E			DRIFT			9469.684	22.328							
60	UQ14		QUAD	N3Q36		9492.012	37.5			UQ14	0.7500	2.400		

Figure 1 f



$p = 29.4$ GeV/c   DPP $= \Delta P/p = \pm 0.12\%$ H13 mom $= -1.165$ in/%, -2.95 mr/%

```
                     8-OCT-81 17:40
RMS PARAMETERS:
ALPHA, BETA, EPSILON (H,V) AT H13: -5.6700  2.2620  0.0064  0.9870  0.1457  0.0064

UQ1  (-2727) UQ2  ( 3235) UD1-3( 2998) UD1-3( 2998) UD1-3( 2998) UQ3-6(-2845) UQ3-6(-2845) UQ3-6(-2845) UQ3-6(-2845) UQ7  ( 1727)
5-6( 3847) UD5-6( 3847) UQ8-9(-3534) UQ8A (  240) UQ8-9(-3534) UQ10 ( 1345) UQ11 (  435) UQ12 (-2916) UQ13 (-2746) UQ14 ( 1894)
 U8%MD    U8%MP    UT%HZ    UT%HX    UT%VZ    UT%VX    TG%UH    TG%UV
  339.76  -204.37  -133.88   31.04    30.02    24.62   256.90   76.09
```

FIGURE 3 a

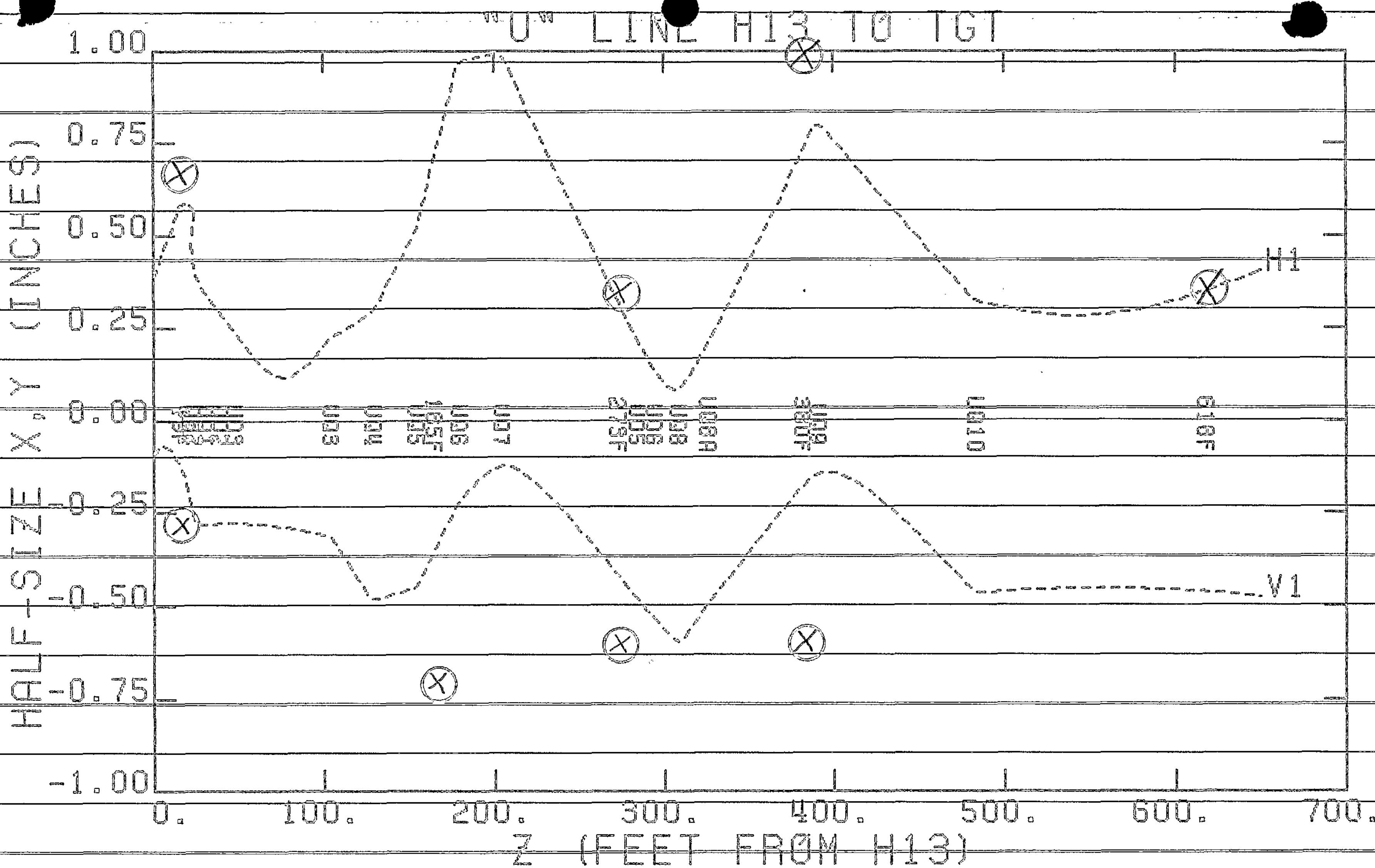
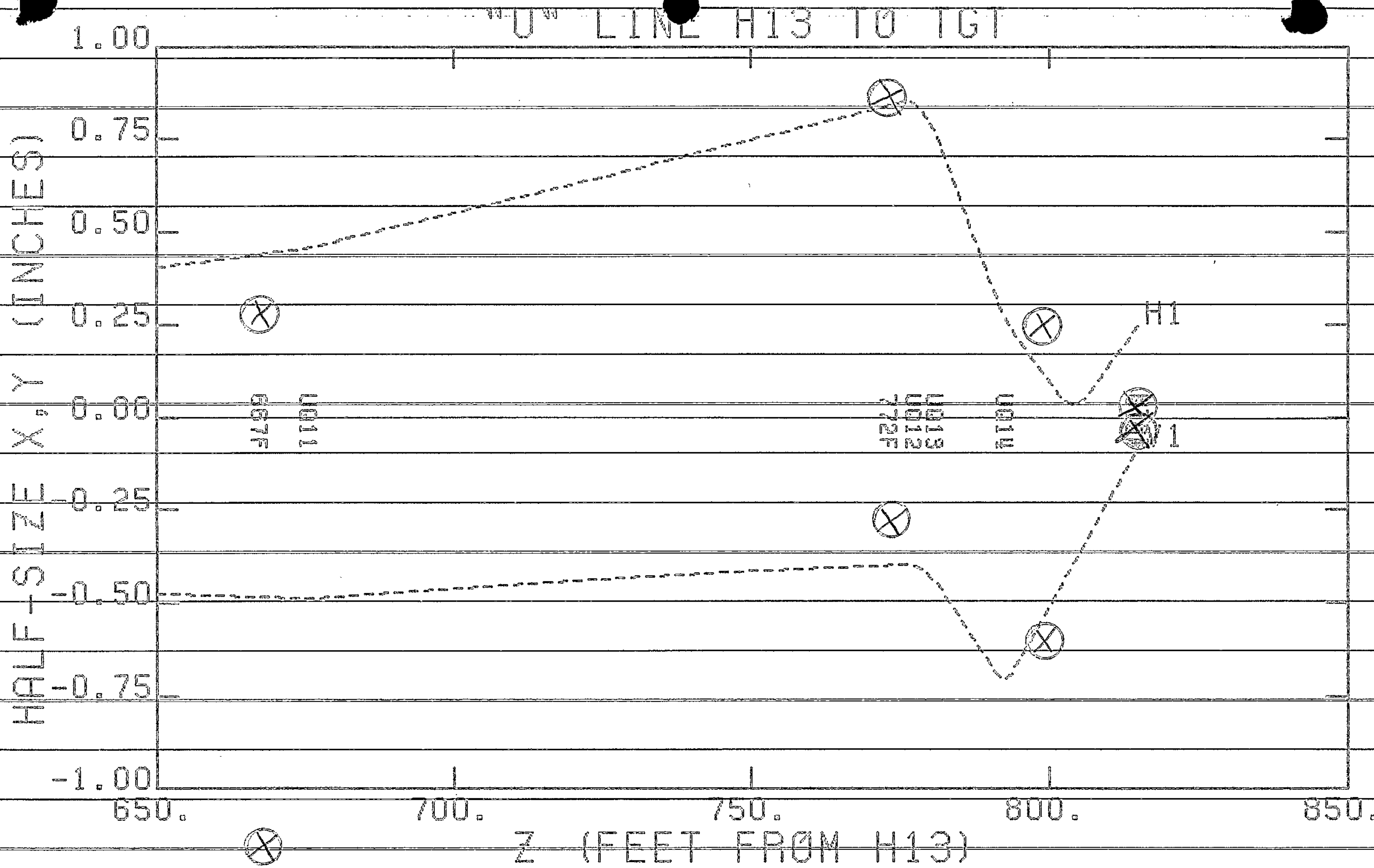
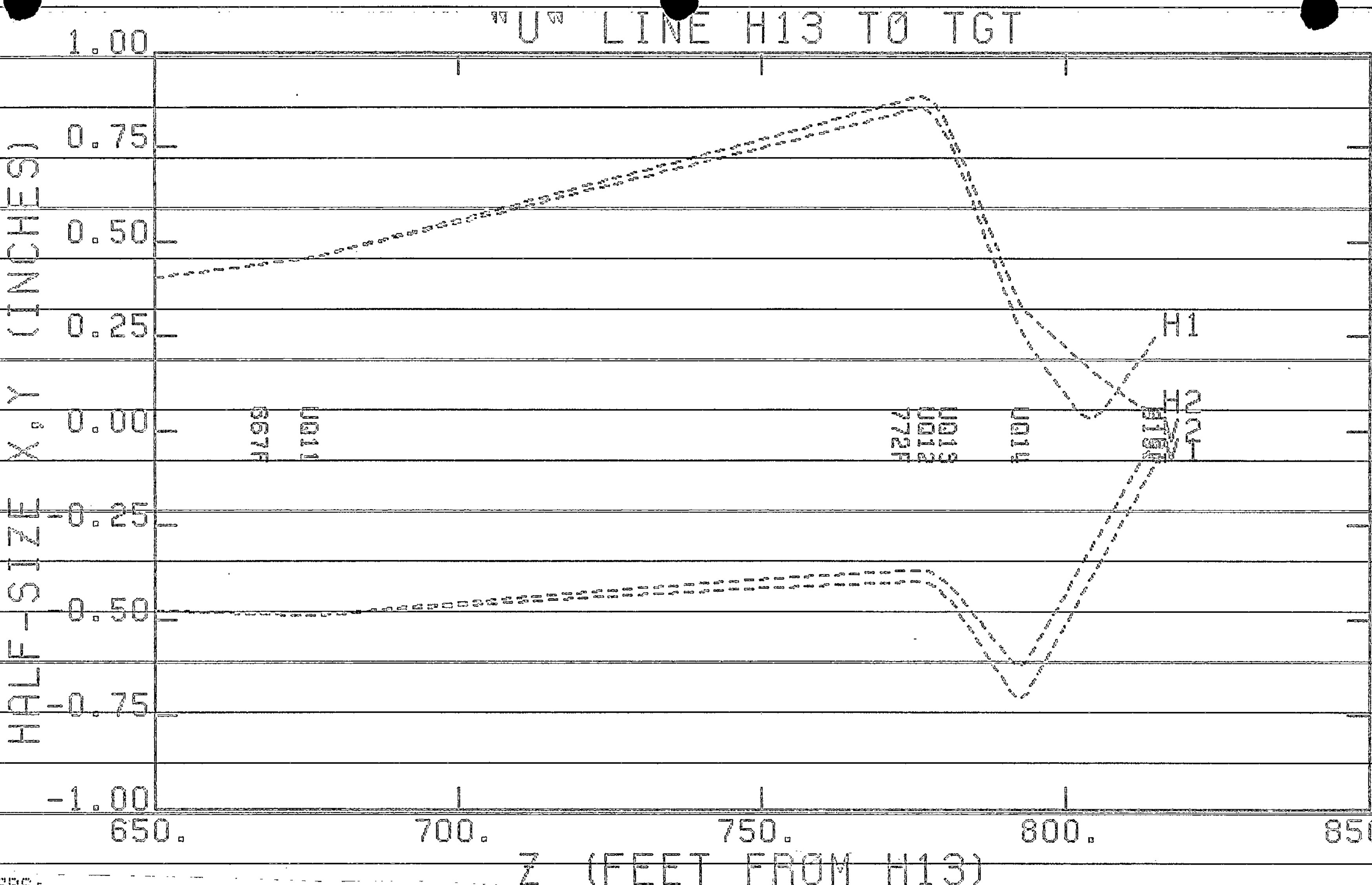


Figure 3 b



"U" LINE H13 TO IGT
HALF-SIZE X, Y (INCHES)
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
650.
700.
750.
800.
850.
Z (FEET FROM H13)
667F
U011
772F
U012
U013
H1
V1

Figure 3 c




```
RMS PARAMETERS:
ALPHA, BETA, EPSILON (H,V) AT H13: -5.6700  2.2620  0.0064  0.9870  0.1457  0.0064

UQ1  (-2727) UQ2  ( 3235) UD1-3( 2998) UD1-3( 2998) UD1-3( 2998) UQ3-6(-2845) UQ3-6(-2845) UQ3-6(-2845) UQ3-6(-2845) UQ7  ( 1727
5-6( 3847) UD5-6( 3847) UQ8-9(-3534) UQ8A (  240) UQ8-9(-3534) UQ10 ( 1345) UQ11 (  435) UQ12 (-2916) UQ13 (-2746) UQ14 ( 1894)
 U8%MD    U8%MP    UT%HZ    UT%HX    UT%VZ    UT%VX    TG%UH    TG%UV
  339.76 -2040.37  -133.88    31.04    30.02    24.62   256.90    76.09


                              21-OCT-81 15:52
RMS PARAMETERS:
ALPHA, BETA, EPSILON (H,V) AT H13: -5.6700  2.2620  0.0064  0.9870  0.1457  0.0064

UQ1  (-2727) UQ2  ( 3235) UD1-3( 2998) UD1-3( 2998) UD1-3( 2998) UQ3-6(-2845) UQ3-6(-2845) UQ3-6(-2845) UQ3-6(-2945) UQ7  ( 1727)
5-6( 3847) UD5-6( 3847) UQ8-9(-3534) UQ8A (  240) UQ8-9(-3534) UQ10 ( 1345) UQ11 (  514) UQ12 (-2689) UQ13 (-2511) UQ14 ( 1963)
 U8%MD    U8%MP    UT%HZ    UT%HX    UT%VZ    UT%VX    TG%UH    TG%UV
  339.76 -2040.37    -1.24    49.22     0.30    25.24    52.78    25.25
```

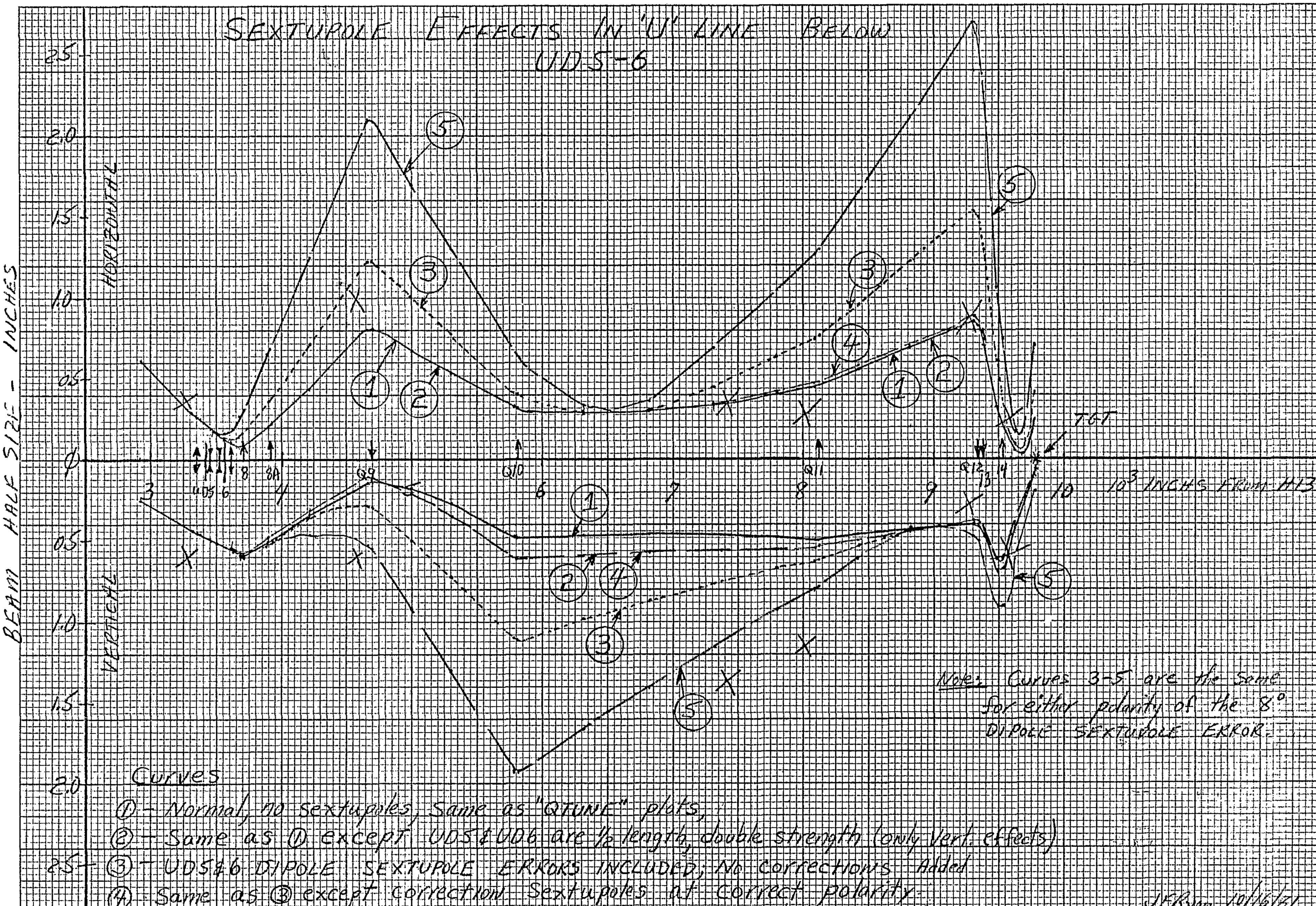
Figure 4

```
" U LINE - H13 THRU UTGT --H13 MOM. DISP & SEXTUPOLES ADDED"
 0
(CHANGE TO INCHES FOR MAGNET SIZES & THOUSAND INCH LENGTH)
15. 1. " IN" 2.54;
15. 8. "KIN" 25.4;
1.  "H13" .365505  .930326  .092763  .894559  0.0  0.12  29.4;
(FOR SECOND ORDER CALC.)
17.  ;
12. "H13" .984801 0. 0. 0. 0. -.7024655;
13.  2.;
3.  0.0;
13.  4.;
(UPDATE R1 & R2 MATRIX & ADD H5 DISPERSION)
14.  1.  0.  0.  0.  0.  -1.165  1.;
14.  0.  1.  0.  0.  0.  -2.95   2.;
13.  1.;
3.  0.0;
( MATRIX ELEM. DIMENSIONS: R16 = INCH/%,  R26= MR/% )
3.  0.21157;
5.  "UQ1" .0375 8.80283 1.;
3.  0.0195;
5.  "UQ2" .0375 -8.73765 1.;
3.  0.0188;
(UD1-3 WITH POLEFACE ROTATION,EACH BEND = 1.4156 DEG)
2.  .7077; 4.  "UD1"  0.0819 11.85804 0.0; 2. 0.7077;
3.  0.018098;
2.  0.7077; 4.  "UD2"  0.0819 11.85804 0.0; 2. 0.7077;
3.  0.018098;
2. 0.7077; 4.  "UD3" .0819 11.85804 0.0; 2. 0.7077;
3.  0.300;
3. 0.32388;
5.  "UQ3"  0.0286 2.00208 1.;
3.  0.27296;
5.  "UQ4"  0.0286 -2.00208 1.;
3. 0.27296;
5.  "UQ5" 0.0286 -2.00208 1.;
3.  0.27296;
5. "UQ6"  0.0286 2.00208 1.;
3. 0.27296;
5.  "UQ7"  0.0286  1.22839 1.;
13.  3.;
3. 0.45806;
3.   0.400;
18. "S1A "  .02606  5.9342  2.063;
3.  0.02047;
(UD5-6 WITH POLEFACE ROTATION, BEND=4.00 DEG)
2.  2.00;  4.  "UD5" 0.0375 68.82688 0.0; 2. 2.00;
18.  "8DSX"  0.0375  -3.4622  2.0;
3.  0.04201;
18.  "8DSX"  0.0375  -3.4622  2.0;
2.  2.00;  4.  "UD6" 0.0375 68.82688 0.0; 2. 2.00;
3.  0.02648;
18. "S1B "  .02606  5.9342  2.063;
3.  0.06310;
5.  "UQ8" .0286  -2.06885  1.0;
3.  .18995;
( UQ8A ONLY VERT. FOCUSING AS WE RAN)
5.  "UQ8A"  .020  -.03679  1.0;
3.  0.300;
3.  0.45281;
```

Figure 5 a

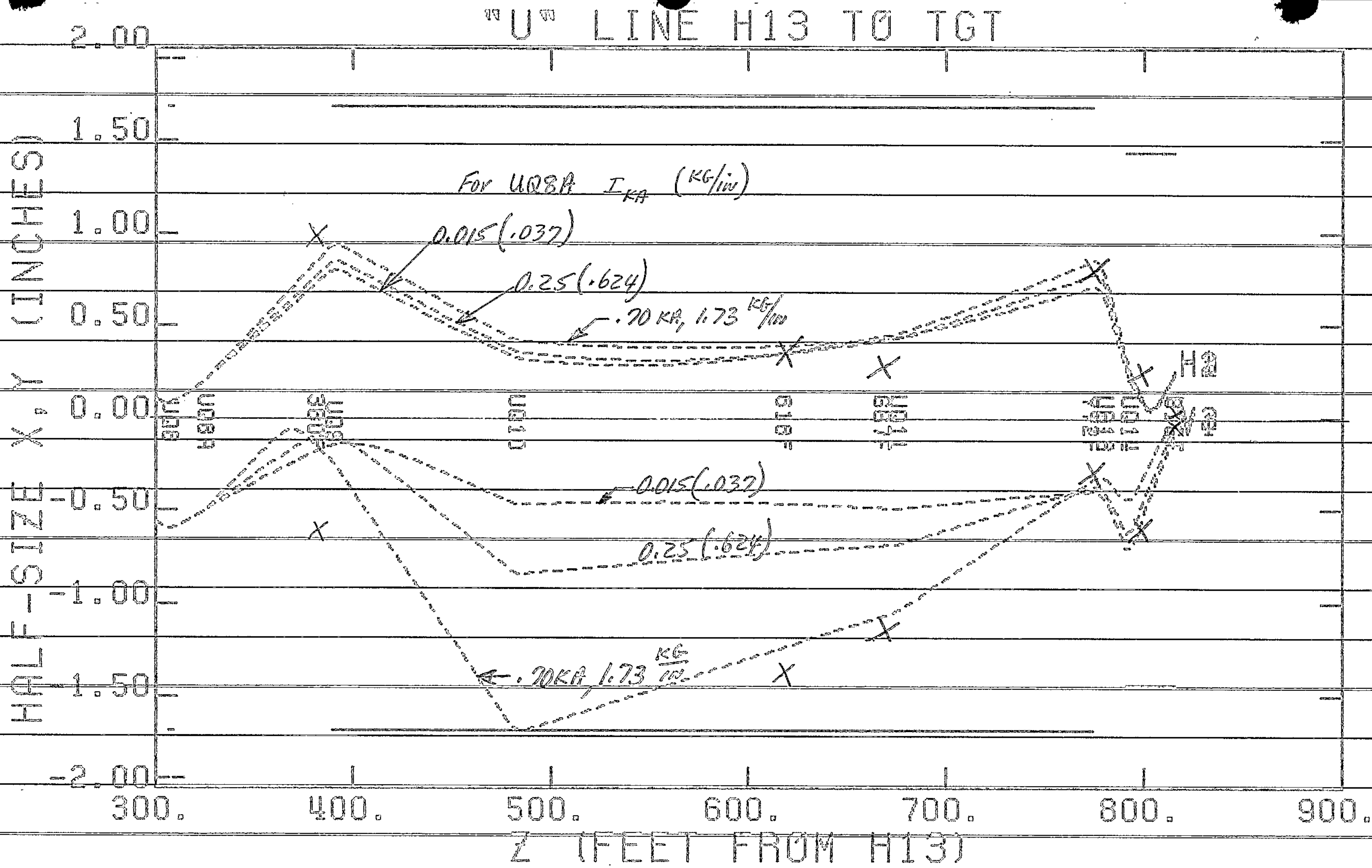
```
5.  "UQ9"  0.0286  2.06885 1.0;
3.  0.300;
3.  .300;
3.  .48126;
5.  "UQ10"  .0286  -1.27525  1.0;
3.  .500;
3.  0.500;
3.  0.500;
3.  0.500;
3.  0.28386;
5.  "UQ11"  0.0286  -0.41439   1.0;
3.  0.300;
3.  0.400;
3.  0.4878;
5.  "UQ12"  0.036  2.71707  1.0;
3.  0.00674;
5.  "UQ13"  0.036  2.55482  1.0;
3.  0.10551;
5.  "UQ14"  0.0375  -6.53737  1.0;
3.  0.100;
3.  0.15315;
13.  4.;
3.  "UTGT"  0.0;
SENTINEL
SENTINEL
```

Figure 5 b



⑤ Same as ③ except Correction Sextupoles at wrong polarity

Figure 6



EFFECT OF VARYING CURRENT IN UQ8A

Figure 7

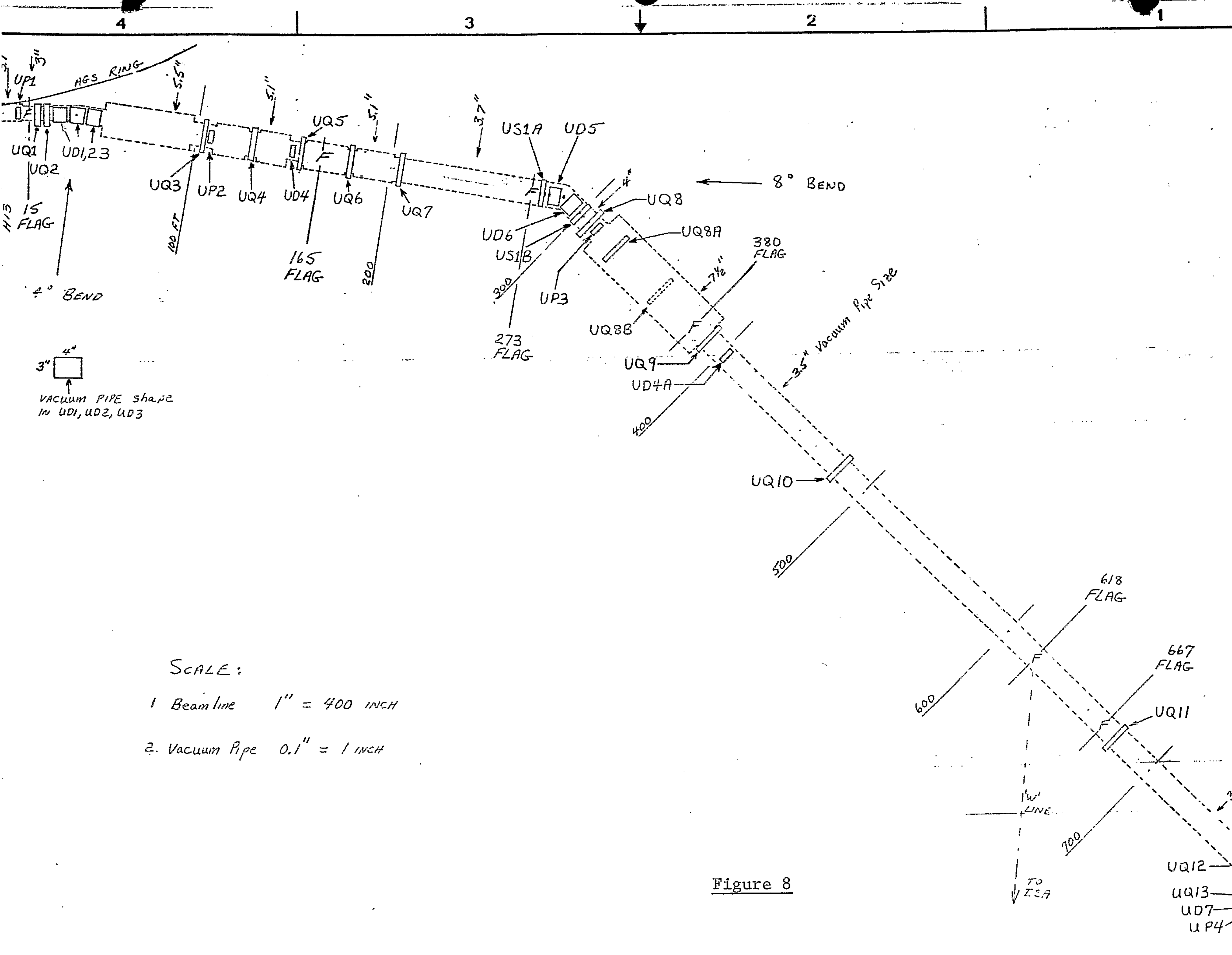

4
3
2
1
UP1
AGS RING
3"
5.5"
5.1"
5.1"
3.7"
UQ1
UQ2
UD1,2,3
UQ3
UP2
UQ4
UD4
UQ5
UQ6
UQ7
US1A
UD5
8° BEND
UQ8
UD6
US1B
UP3
UQ8A
UQ8B
UQ9
UD4A
UQ10
UQ11
UQ12
UQ13
UD7
UP4
15 FLAG
165 FLAG
273 FLAG
380 FLAG
618 FLAG
667 FLAG
100 FT
200
300
400
500
600
700
4"
7½"
3.5" Vacuum Pipe Size
3.5"
4° BEND
4"
3"
VACUUM PIPE shape IN UD1, UD2, UD3
'W' LINE
TO
SCALE:
1 Beam line 1" = 400 INCH
2. Vacuum Pipe 0.1" = 1 INCH

Figure 8