national accelerator laboratory

TM-270
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TWO SECONDARY BEAM LINE QUADRUPOLES

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September 10, 1970

PURPOSE

To design two quadrupoles for consideration in secondary beam lines.

METHOD

Conformal transformations are used to determine pole contours symmetrical about the pole centerline. Application is made to two different quadrupoles. The first is a small aperture high gradient quadrupole in which the symmetrical quadrupole program SQUAD is used directly. The second is a large aperture quadrupole with a pole contour asymmetric about the nominal pole centerline. This gives the minimum stored energy for an asymmetric region of good field. To effect the required asymmetry the pole contours from two SQUAD runs each with a different good field width are adjoined about the nominal centerline of the pole.

RESULTS

Table 1 gives the pole profile as given by SQUAD together with a reasonable magnet outline as estimated from a total flux calculation. The aspect ratio is chosen so that one magnet dimension is as narrow as possible for the current density

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chosen. Table 2 indicates a reasonable cross-section for the excitation coil. The number of conductors is chosen to give a conductor current in the neighborhood of 500A. Table 3 completes the design and performance parameters. Figure 1 shows one quadrant of the quadrupole. Figure 2 indicates the field gradient variation in the midplane, both from SQUAD and an infinite permeability LINDA run. The discrepancy can be traced to the mesh size used in LINDA.

Table 4 gives the pole profile determined by two SQUAD runs, one with a three-inch good field width and one with a five-inch good field width. A reasonable magnet outline is added. In this case an octagonal outside profile is chosen since the intention is to alternate the aspect ratio of the good field region to follow the beam profile. Table 5 locates the critical corners of the coils used to excite the pole. Table 6 indicates the design and performance parameters. Figure 3 shows one quadrant of the magnet cross-section. As shown the horizontal good field width is five inches and the vertical good field width is three inches. Figures 4 and 5 depict the field gradient variation for the five-inch horizontal case and for the three-inch horizontal case. Note in each case the discrepancy between the SQUAD and the corresponding LINDA runs. The coarse mesh necessary in LINDA is responsible for the major part of the difference.

TABLE 1. Outline of Small Aperture Quadrupole

x(in)	y(in)	x(in)	y(in)	x(in)	y(in)
.0000	5.0000	.4515	1.1619	1.2438	.4154
.0000	4.7500	.4719	1.1220	1.2825	.4024
1.5000	4.7500	.4971	1.0754	1.3204	.3927
1.5000	3.6250	.5242	1.0263	1.3578	.3861
.7500	2.1250	.5530	.9755	1.3953	.3824
.4476	1.8028	.5831	.9240	1.4331	.3812
.4333	1.7494	.6181	.8681	1.5029	.3849
.4216	1.7027	.6523	.8190	1.5512	.3909
.4101	1.6532	.6892	.7726	1.6012	.3994
.3994	1.6012	.7292	.7292	1.6532	.4101
.3909	1.5512	.7726	.6892	1.7027	.4216
.3849	1.5029	.8190	.6523	1.7494	.4333
.3812	1.4331	.9240	.5831	1.8028	.4476
.3824	1.3953	.9755	.5530	2.1250	.7500
.3861	1.3578	1.0263	.5242	3.6250	1.5000
.3927	1.3204	1.0754	.4971	4.7500	1.5000
.4024	1.2825	1.1220	.4719	4.7500	.0000
.4154	1.2439	1.1619	.4515	8.0000	.0000
.4318	1.2038	1.2038	.4318	8.0000	5.0000

TABLE 2. Magnet Coils for Small Aperture Quadrupole

x_1(in)	x_2(in)	y_1(in)	y_2(in)	Excit.
.000	.375	1.375	4.750	.3750
.375	.750	2.125	4.750	.2917
.750	1.125	2.875	4.750	.2083
1.125	1.500	3.625	4.750	.1250
1.375	4.750	.000	.375	-.3750
2.125	4.750	.375	.750	-.2917
2.875	4.750	.750	1.125	-.2083
3.625	4.750	1.125	1.500	-.1250

TABLE 3. Small Aperture Quadrupole Parameters

Field Gradient	12 kG/in
Aperture	2 1/16 in Dia.
Width of Good Field	2 in Dia.
Magnet Length	120 in
Coil Turns per Pole	24
Copper Conductor Cross Section (square)	.340 in
Water Cooling Hole Diameter	.170 in
Conductor Corner Radius	.031 in
Conductor Current (approximate)	550 A
Current Density in Conductor	5975 A/in^2
Average Conductor Turn Length	256 in
Coil Resistance per Pole	.049 ohms
Voltage Drop per Pole	27 V
Power per Pole	14.8 kW
Cooling Water Pressure	100 psi
Number of Water Paths per Pole	6
Water Flow	3.5 GPM
Temperature Rise	16° C (61° F)
Outside Dimensions	10 in by 16 in

TABLE 4. Large Aperture Asymmetric Quadrupole Outline

x(in)	y(in)	x(in)	y(in)	x(in)	y(in)
.0000	10.5000	1.0581	2.1000	2.2601	1.0000
.0000	7.0000	1.1000	2.0460	2.3000	.9827
2.3000	7.0000	1.1341	2.0000	2.4000	.9416
2.3000	5.5000	1.2000	1.9040	2.5000	.9033
1.1916	3.4000	1.2027	1.9000	2.6000	.8671
1.1508	3.3000	1.2676	1.8000	2.7000	.8324
1.1107	3.2000	1.3358	1.7000	2.8000	.7988
1.1000	3.1730	1.4000	1.6161	2.9000	.7668
1.0714	3.1000	1.4134	1.6000	3.0000	.7379
1.0334	3.0000	1.5000	1.5052	3.1000	.7147
1.0000	2.9081	1.5052	1.5000	3.2000	.7001
.9972	2.9000	1.6128	1.4000	3.3000	.6952
.9636	2.8000	1.7000	1.3283	3.4000	.6999
.9340	2.7000	1.7370	1.3000	3.5000	.7126
.9105	2.6000	1.8000	1.2546	3.6000	.7317
.9000	2.5339	1.8821	1.2000	3.7000	.7555
.8967	2.5000	1.9000	1.1887	3.8000	.7827
.8985	2.4000	2.0000	1.1295	6.8000	2.3000
.9247	2.3000	2.0539	1.1000	8.3000	2.3000
.9816	2.2000	2.1000	1.0760	8.3000	.0000
1.0000	2.1747	2.2000	1.0272	10.5000	.0000
				10.5000	10.5000

TABLE 5. Coil Locations for Asymmetric Quadrupole

x_1(in)	x_2(in)	y_1(in)	y_2(in)	Excit.
.0000	.7500	2.5000	7.0000	.5000
.7500	1.5000	4.0000	7.0000	.3333
1.5000	2.2500	5.5000	7.0000	.1667
3.8000	8.3000	.0000	.7500	-.5000
5.3000	8.3000	.7500	1.5000	-.3333
6.8000	8.3000	1.5000	2.2500	-.1667

TABLE 6. Composite Quadrupole Parameters

Field Gradient	5.65 kG/in
Aperture	4.25 in Dia.
Width of Good Field	3 in by 5 in
Magnet Length	120 in
Coil Turns per Pole	48
Copper Conductor Cross Section (square)	.340 in
Water Cooling Hole Diameter	.170 in
Conductor Corner Radius	.03125 in
Conductor Current (approximate)	550 A
Current Density in Conductor	5975 A/in^2
Average Conductor Turn Length	265 in
Coil Resistance per Pole	.101 ohms
Voltage Drop per Pole	55.7 V
Power per Pole	30.6 kW
Cooling Water Pressure	100 psi
Number of Water Paths per Pole	12
Water Flow	6.9 GPM
Temperature Rise	16.8° C (62.2° F)
Outside Dimensions	21 in by 21 in

Subject

SMALL APERTURE QUADRUPOLE

GRADIENT 12 kG/in
APERTURE 2 1/16 in Dia.
GOOD FIELD WIDTH 2 in Dia.
RUN SQUAD 9/8/70

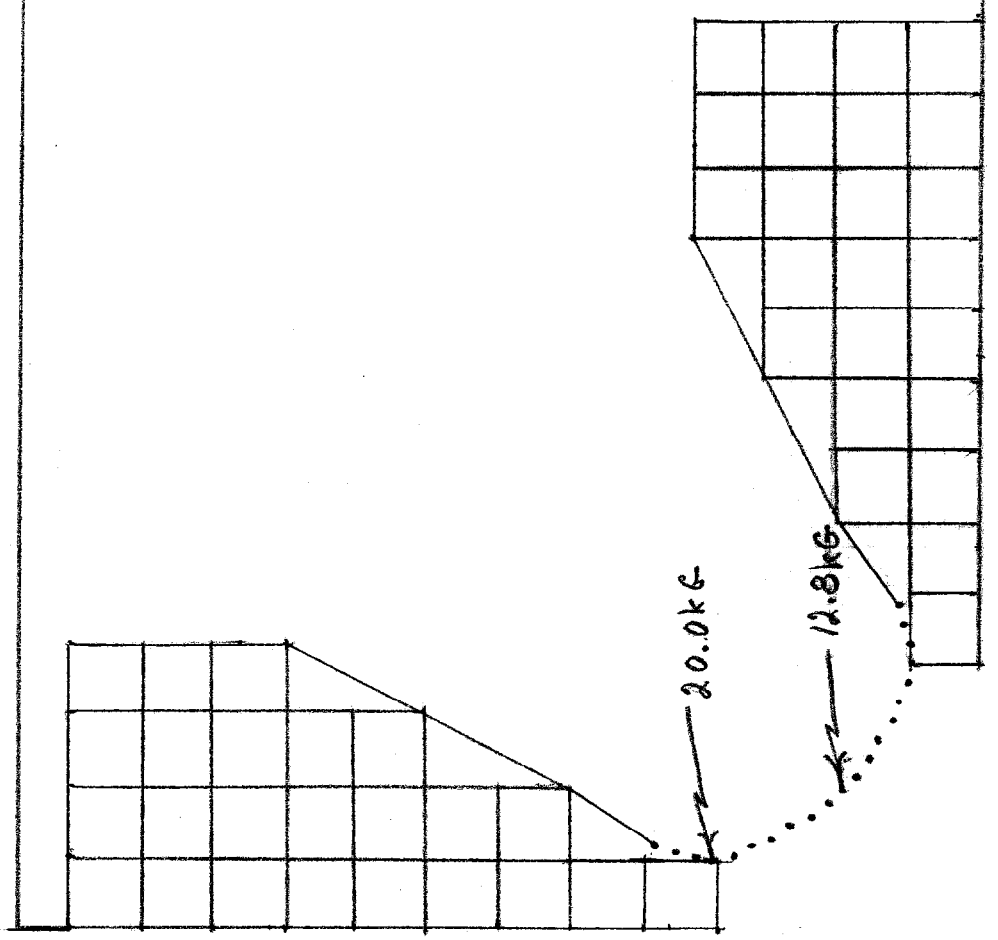

FIG. 1

Subject

SMALL APERTURE QUADRUPOLE

PROFILE - SQUAD (6600) 9/8/70

APERTURE - $2\frac{1}{16}$ in.

GRADIENT - 12 kG/in

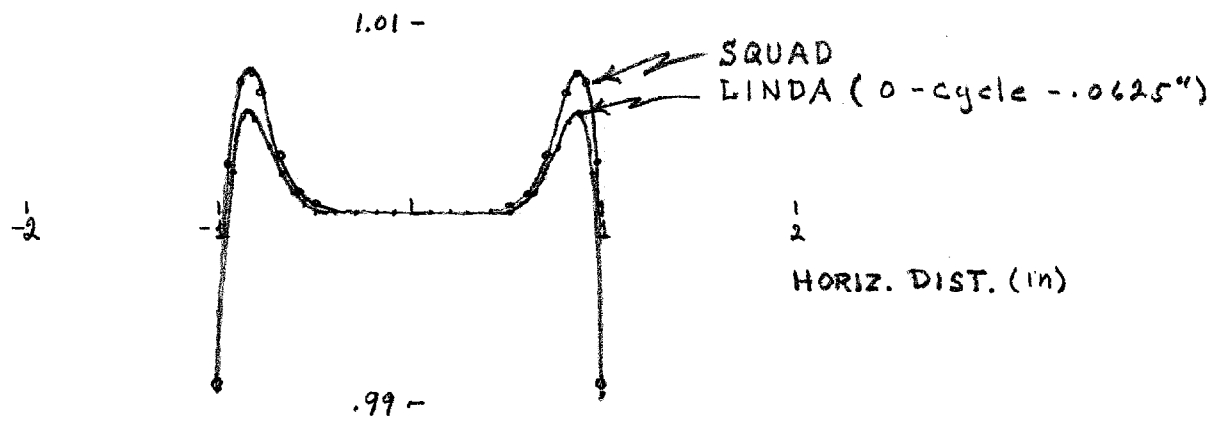

FIG. 2.

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J.C. [illegible]

SECONDARY BEAM LINE QUADRUPOLE

APERTURE	4.25"
HORIZONTAL GOOD FIELD WIDTH	5.0"
VERTICAL GOOD FIELD WIDTH	3.0"
OUTSIDE DIMENSIONS	21"×21"
QUADRUPOLE STRENGTH	5.65 kG/in

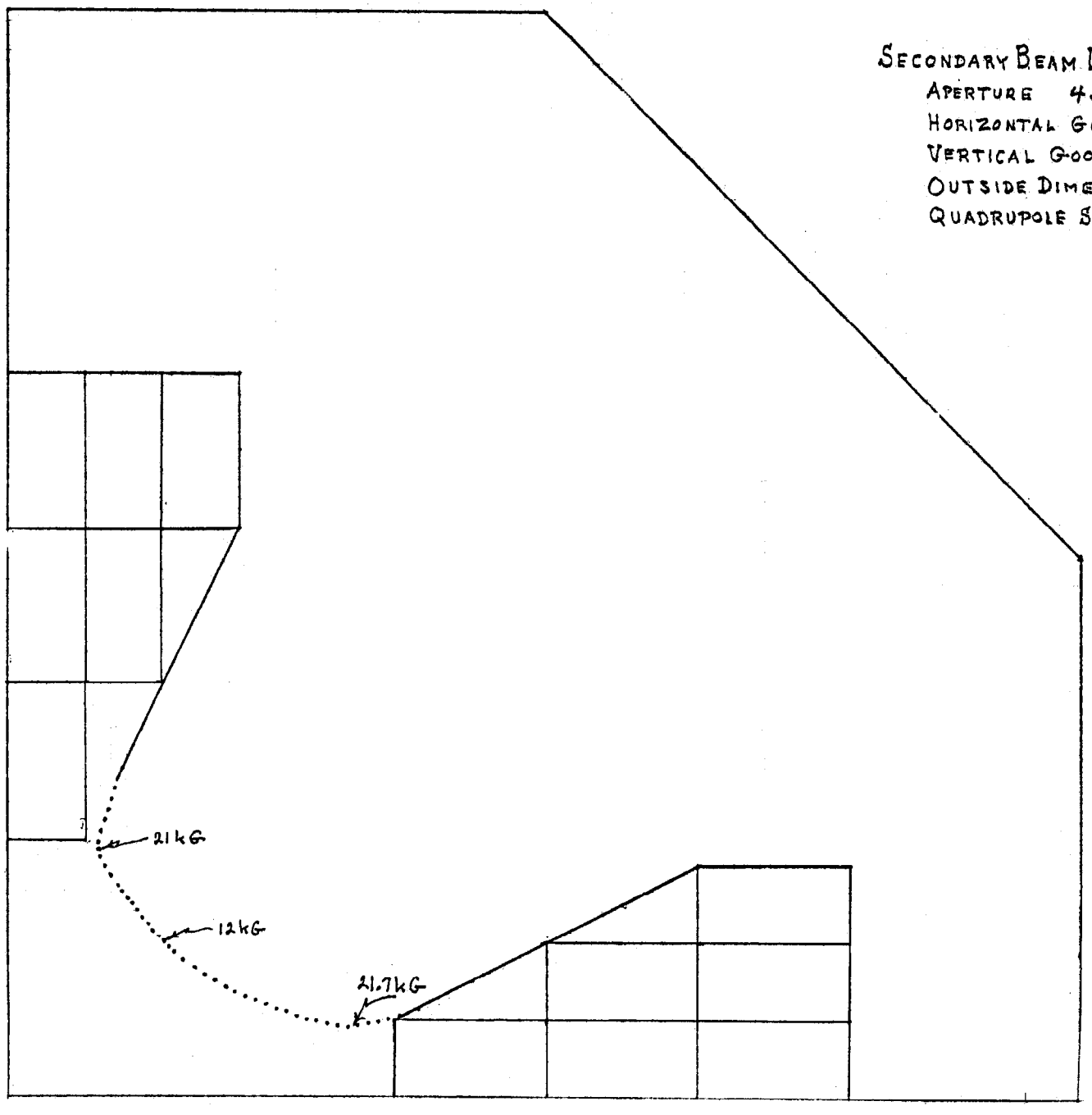

FIG. 3

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COMPOSITE QUADRUPOLE

SQUAD (GFLD = 5")
CRUNCH (GQPOLE; SQUAD(3") + SQUAD(5"))
LINDA (Zero Cycle - .100" mesh)

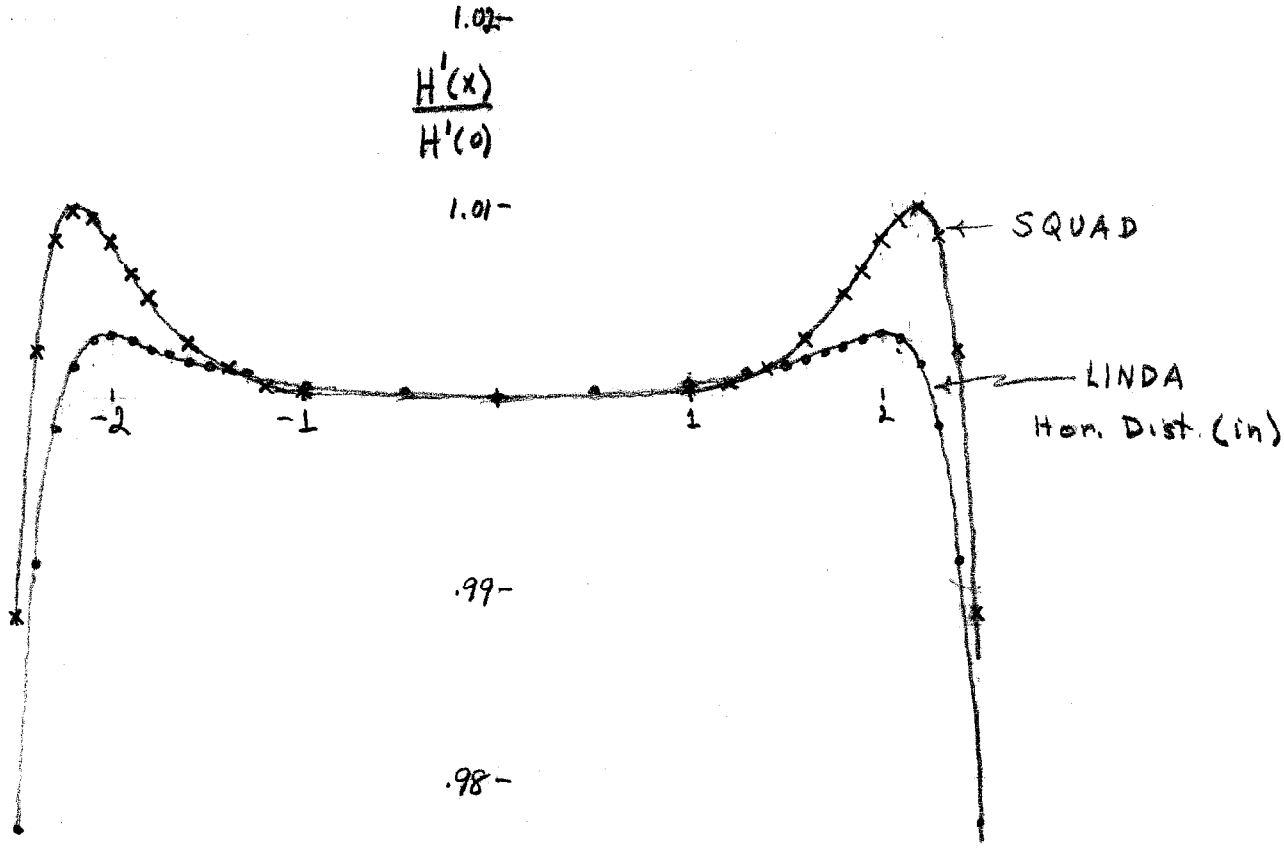

FIG. 4

COMPOSITE QUADRUPOLE

SQUAD (GFLD = 3")

CRUNCH (GQPOLE; SQUAD(5")+SQUAD(8"))

LINDA (ZERO CYCLE -.100" MESH)

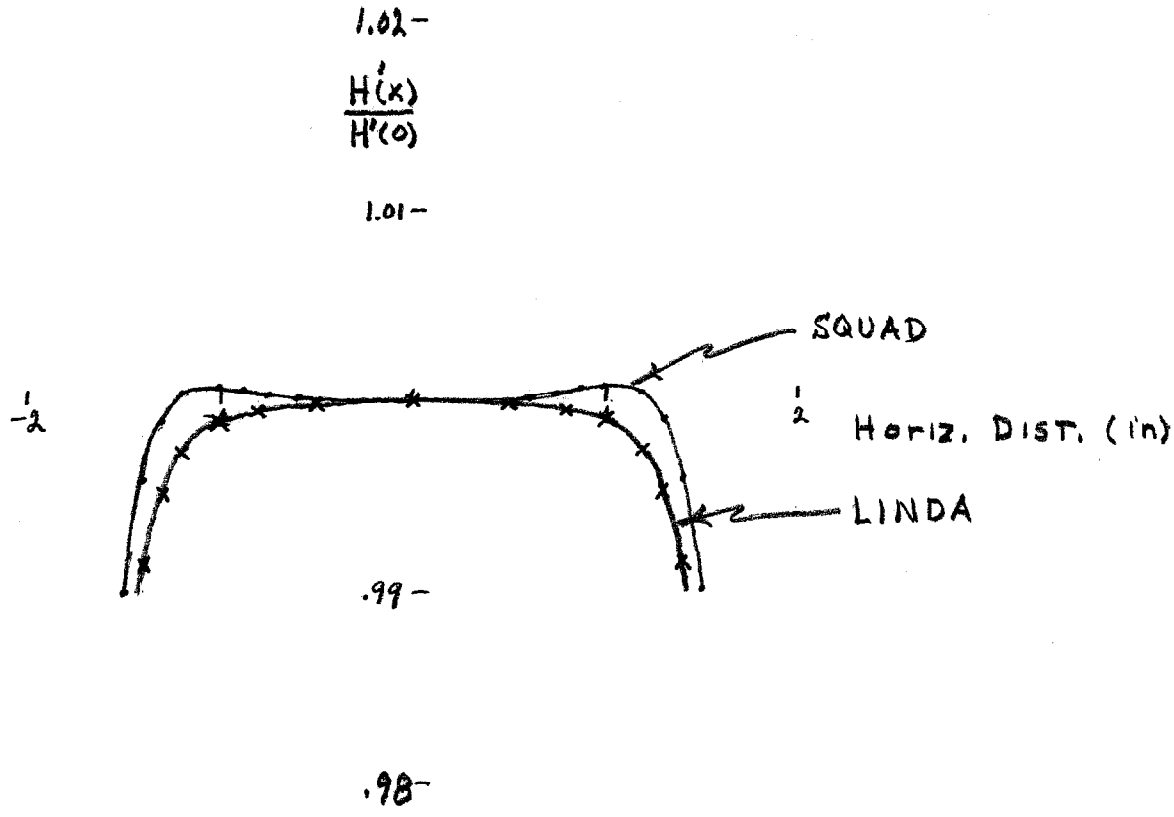

FIG. 5