PS/AA/ACOL Note 30

MAGNETIC STUDIES ON QDC53 USING THE TOSCA CODE

M R Harold

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Introduction

At R. Sherwood's suggestion, the last quadrupole in the injection line to ACOL is to be combined with one of the lattice quadrupoles, QDC53, to form a "normal" quadrupole the two halves of which are split vertically by a tapered neutral pole (see figure 1). The magnet is to be made from QN laminations and coils, and the magnetic effect of the neutral pole is required to be known. All results quoted below are for a core length of 60 cm (as for the QN), with non-linear iron.

Two-Dimensional Work

As a first step the quadrupole was modelled on PE2D, the neutral pole having a half thickness of 85mm. The mesh is shown in figure 2, and the flux line distribution in figure 4, the ampere turns being 27476 per pole. Later, a 2 mm air gap was introduced between the two half-quadrupoles in order to take account of the fact that each half will need to be independently adjusted in position. The air gap made no significant difference to the field distribution seen by the beam, but did cause much more flux to travel down the neutral pole rather than across it (compare figures 4 and 5). The horizontal field component in the air gap was computed (see Appendix I), but of course these values will vary rapidly depending on the size of the air gap.

The field gradient within the aperture of the quadrupole was as expected (figure 3), with no untoward perturbation close to the neutral pole. The pole profile contains a 12-pole correction to counteract end effects, and the variation of $\Delta g/g_5$ vs x agrees well with previous computations on the QN. The central gradient g_5 is here taken as dBy/dx at x=5 cm, the approximate beam position.

Three-Dimensional Work

Having established the shape of the field in the centre ($z=0$), the quadrupole was then run on TOSCA. First, the half-neutral pole (thickness 8.5 cm) was assumed parallel-sided, so that only half the azimuthal length of the magnet needed modelling (QNH). The neutral pole overhang of 12 cm just exceeded the coil overhang, so as not to interfere with other equipment. Later, the tapered pole was introduced (QNW), and then the 2 mm air gap (QQQ). The field integrals for all three cases are given in Appendix II, the energization being 28036.8 A-t per pole.

The mesh, shown in figures 6 and 7 is necessarily coarser than that used for the QN because of the need to keep computation times within reasonable limits (e.g. <1 hr.). The intention was to adjust the mesh until TOSCA gave the same field distribution at $z=0$ as that given by PE2D. However, the rather "noisy" results shown in figure 8 were regarded as satisfactory for the following reasons:

a). the field integrals did not show the discontinuities apparent at $z=0$ (which seems to be typical of TOSCA)

b). the size of the problem was already quite large

c). we were primarily interested in end effects, which are possibly not so mesh dependant.

The variation of $\Delta G/G_5$ across the aperture remained essentially the same for all three cases, and is shown in figure 9. The end-fields contain appreciable dipole components which would be removed if the neutral pole could be made infinitely long, or compensated for by displacing the magnet transversely by about 0.7 mm. In the case of the tapered pole, the dipole components differ from end to end, and this might need to be taken into account.

A simple analysis of the field in QNW yields (in gauss-cm)

$$\int_{-97}^{97} B_y \, dz = 2951.38 + 40455.73x + 8.59 \, (5.5-x)^2$$

The sextupole term is weak, and should be readily removed either by machining the end shims or by the use of washers.

APPENDIX I

Horizontal field component (gauss) in the 2 mm air gap between neutral poles (PE2D).

VALUES OF BX ALONG LINE.

X POSITION	Y POSITION	VALUE
-8.60000	0.00000000	-0.00551
-8.60000	1.00000	-7.00691
-8.60000	2.00000	-14.4392
-8.60000	3.00000	-20.9483
-8.60000	4.00000	-27.8407
-8.60000	5.00000	-33.9294
-8.60000	6.00000	-39.2979
-8.60000	7.00000	-44.1981
-8.60000	8.00000	-48.4356
-8.60000	9.00000	-51.5892
-8.60000	10.00000	-53.9451
-8.60000	11.0000	-54.9943
-8.60000	12.0000	-55.1960
-8.60000	13.0000	-53.6960
-8.60000	14.0000	-51.1032
-8.60000	15.0000	-46.7921
-8.60000	16.0000	-41.2792
-8.60000	17.0000	-33.9657
-8.60000	18.0000	-24.2581
-8.60000	19.0000	-14.5510
-8.60000	20.0000	0.19910
-8.60000	21.0000	14.9488
-8.60000	22.0000	34.7781
-8.60000	23.0000	54.6034
-8.60000	24.0000	78.1722
-8.60000	25.0000	103.320
-8.60000	26.0000	133.006
-8.60000	27.0000	169.410
-8.60000	28.0000	205.813
-8.60000	29.0000	242.218
-8.60000	30.0000	281.477
-8.60000	31.0000	331.940
-8.60000	32.0000	382.406
-8.60000	33.0000	432.870
-8.60000	34.0000	483.343
-8.60000	35.0000	509.723
-8.60000	36.0000	536.093
-8.60000	37.0000	562.463
-8.60000	38.0000	588.834
-8.60000	39.0000	615.204
-8.60000	40.0000	641.574
-8.60000	41.0000	667.946
-8.60000	42.0000	659.864
-8.60000	43.0000	617.371
-8.60000	44.0000	574.878
-8.60000	45.0000	532.383
-8.60000	46.0000	489.890
-8.60000	47.0000	447.397
-8.60000	48.0000	404.903
-8.60000	49.0000	362.399
-8.60000	50.0000	345.183
-8.60000	51.0000	327.990
-8.60000	52.0000	310.796
-8.60000	53.0000	293.600
-8.60000	54.0000	276.407
-8.60000	55.0000	259.212
-8.60000	56.0000	242.019
-8.60000	57.0000	224.824
-8.60000	58.0000	207.630
-8.60000	59.0000	190.436
-8.60000	60.0000	173.241
-8.60000	61.0000	156.048
-8.60000	62.0000	138.853
-8.60000	63.0000	121.659
-8.60000	64.0000	104.464
-8.60000	65.0000	87.2706
-8.60000	66.0000	70.0763
-8.60000	67.0000	52.8821
-8.60000	68.0000	35.6880
-8.60000	69.0000	18.4938
-8.60000	70.0000	1.27990

APPENDIX II

TOSCA fields and field integrals in gauss.

QNW

Y=0	X	$(B_y)_o$	$\int_o^{97} B_y dz$	$\int_{-97}^{o} B_y dz$	$\int_{-97}^{97} B_y dz$
	0	0.77	1455.96	1759.05	3215.01
	1	568.83	21648.8	21932.6	43581.4
	2	1137.0	41849.2	42113.3	83962.5
	3	1704.8	62059.8	62304.4	124364.2
	4	2273.1	82285.8	82516.3	164802.1
	5	2842.9	102507.0	102723.0	205230.0
	6	3414.4	122758.0	122960.0	245718.0
	7	3979.8	143005.0	143194.0	286199.0
	8	4547.3	163250.0	163428.0	326678.0
	9	5122.2	183496.0	183662.0	367158.0
	10	5702.8	203763.0	203919.0	407682.0
	11	6289.8	224079.0	224226.0	448305.0
	12	6888.8	244452.0	244591.0	489043.0
	13	7484.4	264948.0	265079.0	530027.0
	14	8127.4	285517.0	285640.0	571157.0

X=5	Y	$(B_x)_o$	$\int_o^{97} B_x dz$	$\int_{-97}^{o} B_x dz$	$\int_{-97}^{97} B_x dz$
	0	0.0	0.0	0.0	0.0
	1	570.38	20235.2	20218.3	40453.5
	2	1133.6	40438.9	40410.7	80849.6
	3	1704.0	60768.0	60725.8	121493.8
	4	2267.8	80963.1	80908.0	161871.1
	5	2835.1	101350.0	101281.0	202631.0
	6	3396.5	121646.0	121565.0	243211.0
	7	3966.3	142133.0	142040.0	284173.0
	8	4514.7	161810.0	161710.0	323520.0

g_5 = 570.515 g/cm

G_5 = 40455.725 g-cm/cm

L_{eff} = 70.911 cm

QNH

Y=0	X	$(B_y)_o$	$\int_0^{97} B_y dz$	$\int_{-97}^{0} B_y dz$	$\int_{-97}^{97} B_y dz$
	0	0.67	1589.67	1589.67	3179.34
	1	568.76	21767.1	21767.1	43534.2
	2	1136.9	41961.6	41961.6	83923.2
	3	1704.8	62166.0	62166.0	124332.0
	4	2273.0	82385.7	82385.7	164771.4
	5	2842.9	102604.0	102604.0	205208.0
	6	3414.4	122852.0	122852.0	245704.0
	7	3979.8	143093.0	143093.0	286186.0
	8	4547.4	163332.0	163332.0	326664.0
	9	5122.4	183575.0	183575.0	367150.0
	10	5703.1	203840.0	203840.0	407680.0
	11	6290.1	224154.0	224154.0	448308.0
	12	6889.1	244528.0	244528.0	489056.0
	13	7484.8	265018.0	265018.0	530036.0
	14	8127.8	285620.0	285620.0	571240.0

X=5	Y	$(B_x)_o$	$\int_0^{97} B_x dz$	$\int_{-97}^{0} B_x dz$	$\int_{-97}^{97} B_x dz$
	0	0.0	0.0	0.0	0.0
	1	570.39	20229.4	20229.4	40458.8
	2	1133.6	40427.3	40427.3	80854.6
	3	1704.0	60752.6	60752.6	121505.2
	4	2267.8	80942.1	80942.1	161884.2
	5	2835.1	101322.0	101322.0	202644.0
	6	3396.5	121613.0	121613.0	243226.0
	7	3966.3	142111.0	142111.0	284222.0
	8	4514.6	161796.0	161796.0	323592.0

g_5 = 570.545 g/cm

G_5 = 40462.55 g-cm/cm

L_{eff} = 70.919 cm

QQQ

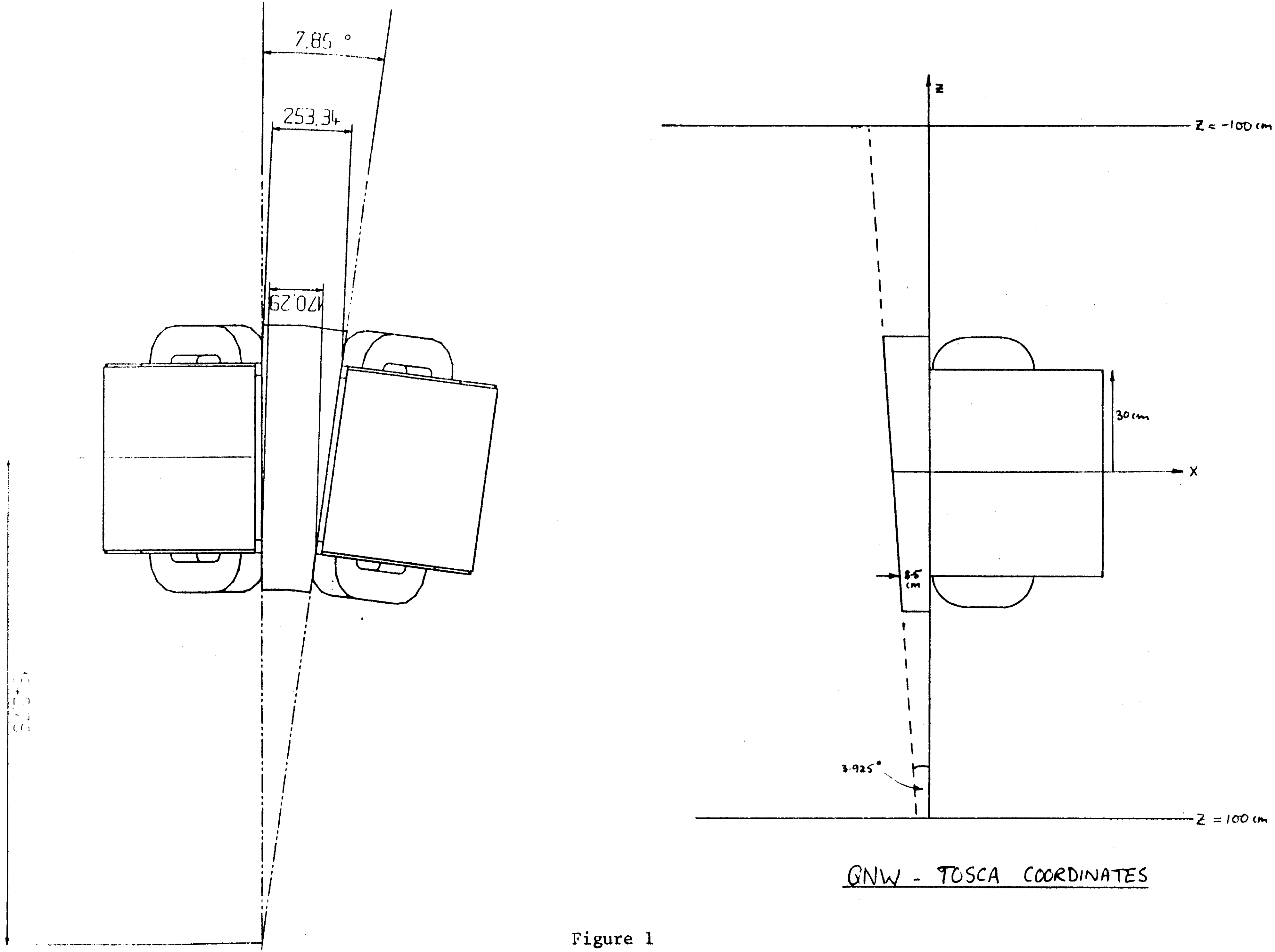
Y=0	X	$(B_y)_o$	$\int_{o}^{97} B_y dz$	$\int_{-97}^{o} B_y dz$	$\int_{-97}^{97} B_y dz$
	0	0.71	1459.07	1740.23	3199.3
	1	568.42	21637.7	21901.8	43539.5
	2	1136.2	41824.1	42070.6	83894.7
	3	1703.7	62021.0	62251.8	124272.8
	4	2271.6	82233.4	82450.0	164683.4
	5	2841.1	102442.0	102645.0	205087.0
	6	3412.3	122679.0	122870.0	245549.0
	7	3977.3	142913.0	143092.0	286005.0
	8	4544.5	163145.0	163314.0	326459.0
	9	5119.0	183377.0	183536.0	366913.0
	10	5699.3	203632.0	203781.0	407413.0
	11	6285.9	223935.0	224076.0	448011.0
	12	6884.6	244296.0	244429.0	488725.0
	13	7479.8	264780.0	264906.0	529686.0
	14	8122.4	285336.0	285454.0	570790.0

X=5	Y	$(B\ )_o$	$\int_{o}^{97} B_x dz$	$\int_{-97}^{o} B_x dz$	$\int_{-97}^{97} B_x dz$
	0	0.0	0.0	0.0	0.0
	1	570.04	20219.3	20206.5	40425.8
	2	1132.9	40412.4	40387.2	80799.6
	3	1702.9	60728.2	60690.4	121418.6
	4	2266.5	80910.3	80861.0	161771.3
	5	2833.4	101284.0	101223.0	202507.0
	6	3394.5	121567.0	121495.0	243062.0
	7	3963.9	142041.0	141959.0	284000.0
	8	4512.1	161707.0	161618.0	323325.0

g_5 = 570.195 g/cm

G_5 = 40429.3 g-cm/cm

L_{eff} = 70.904 cm



7.85 °
253.34
170.29
z
Z = -100 cm
30 cm
X
8.5 cm
3.925°
Z = 100 cm
QNW - TOSCA COORDINATES

Figure 1

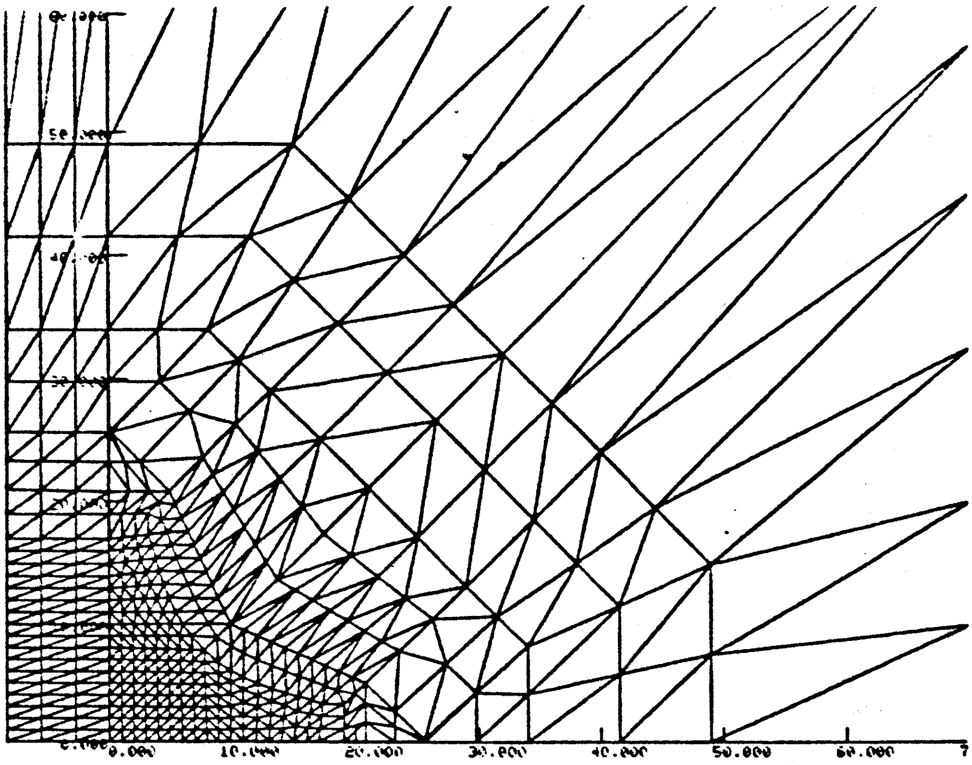


Figure 2

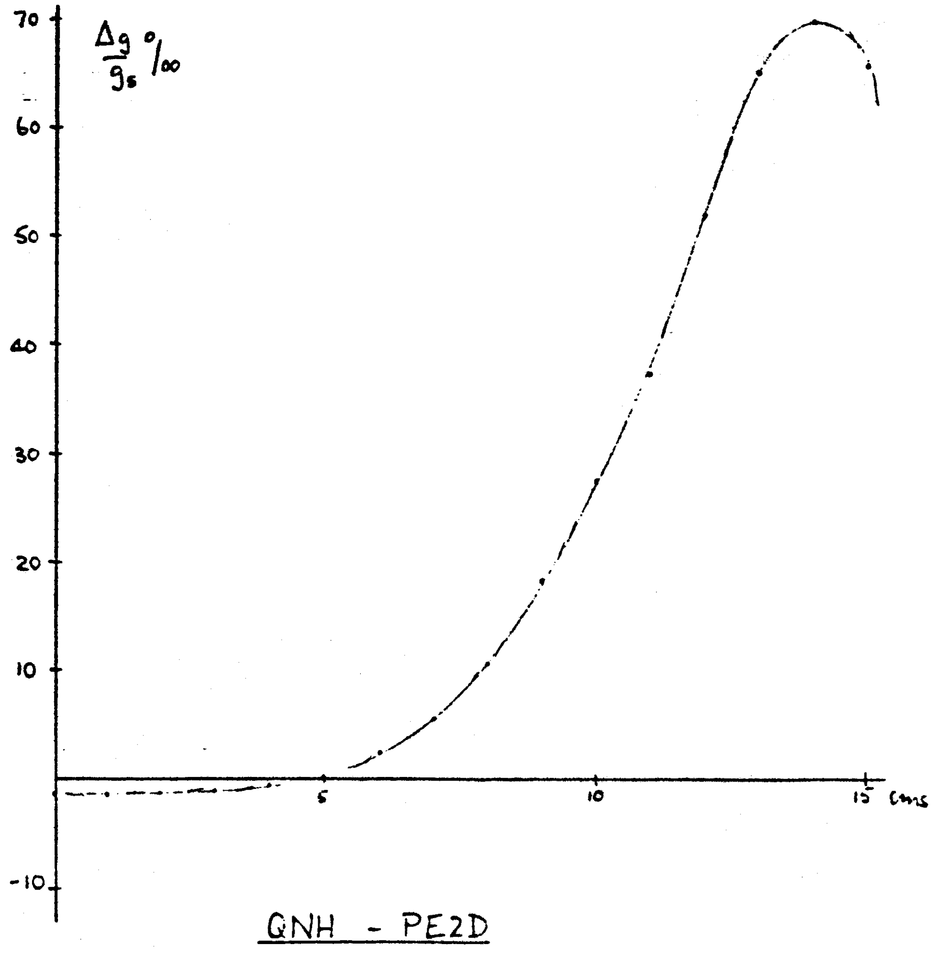


Figure 3

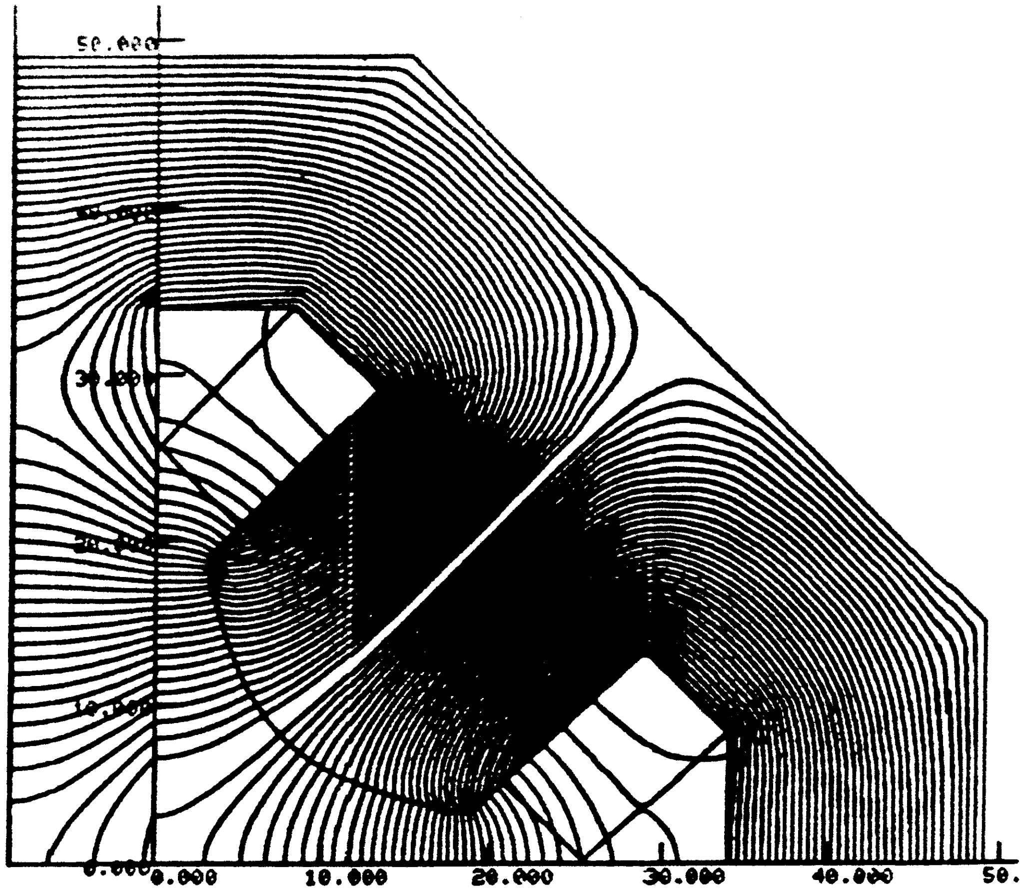
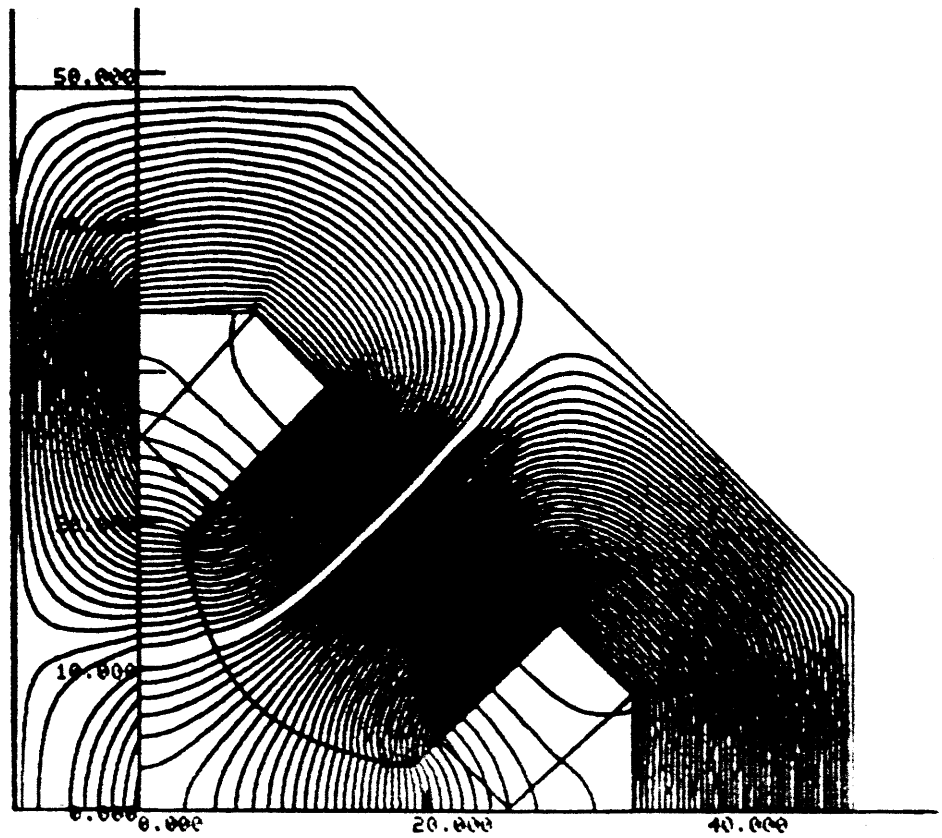


Figure 4



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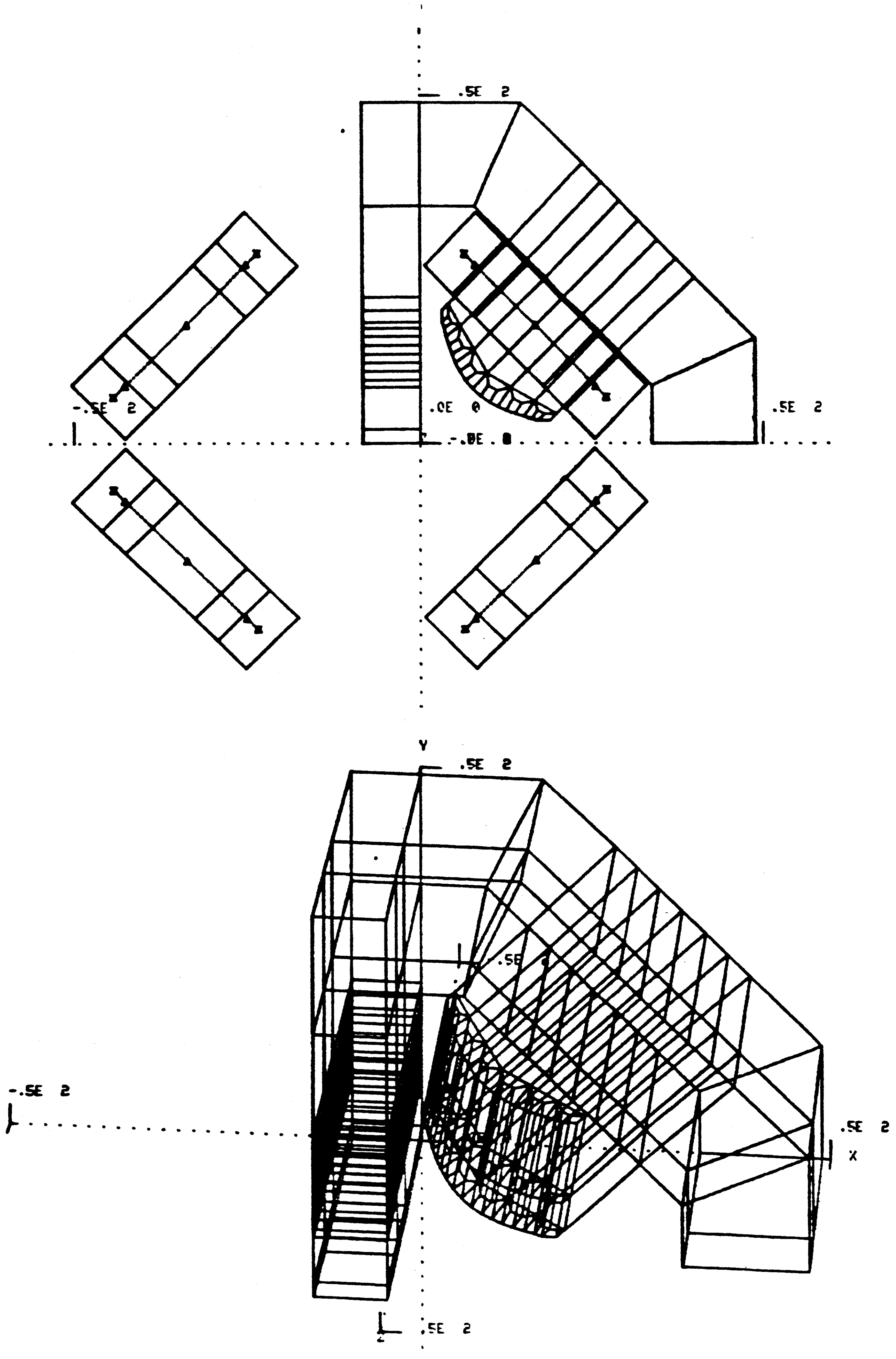
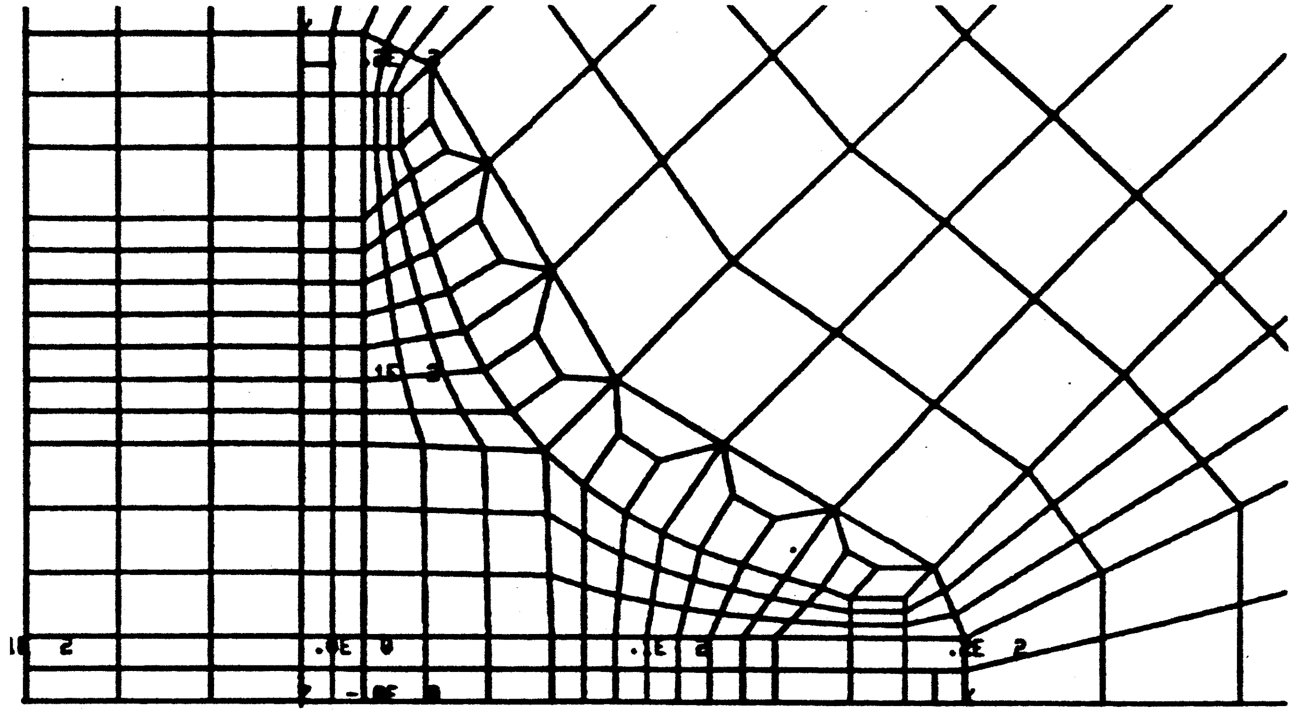


Figure 6 QNH



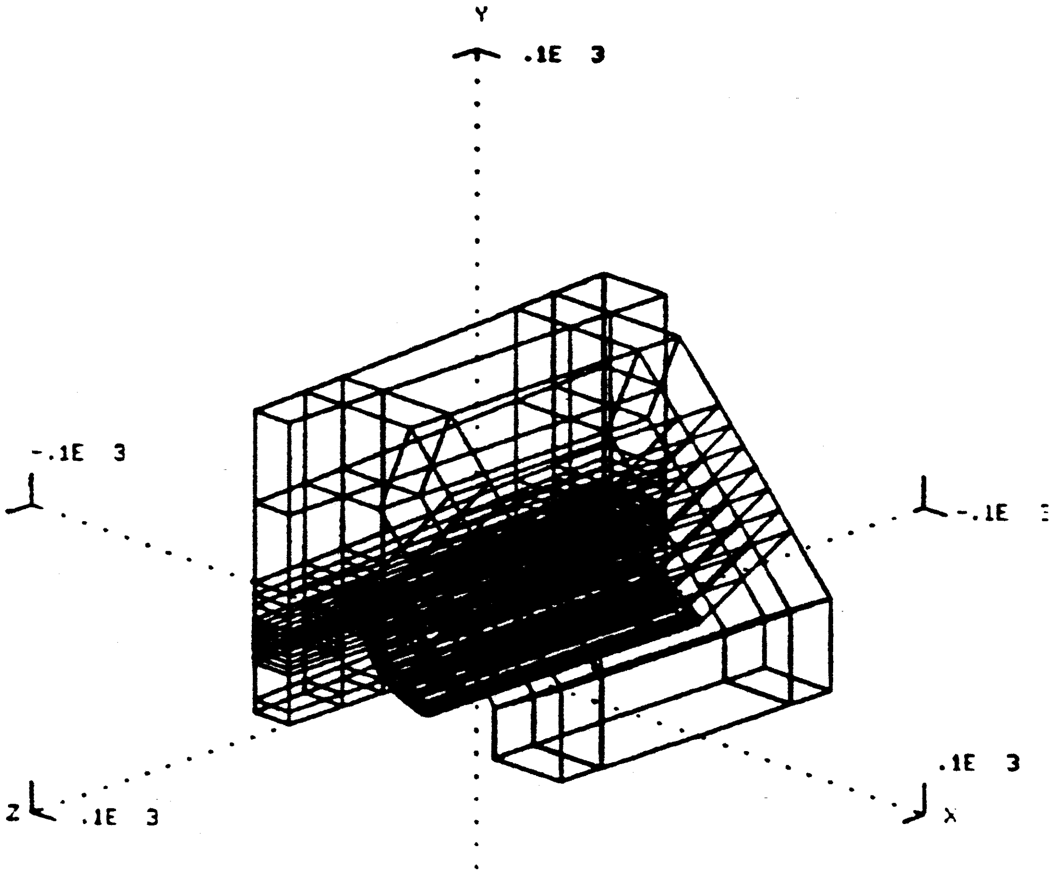


Figure 7 QNW

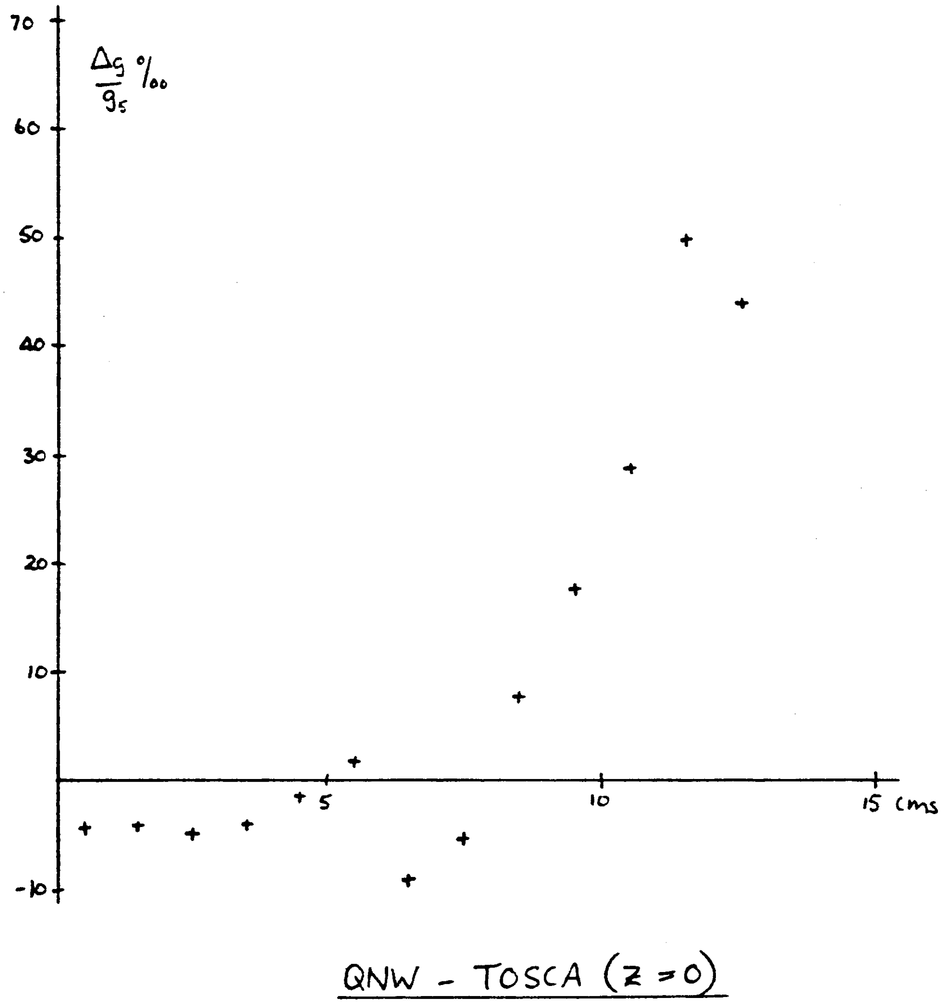


Figure 8

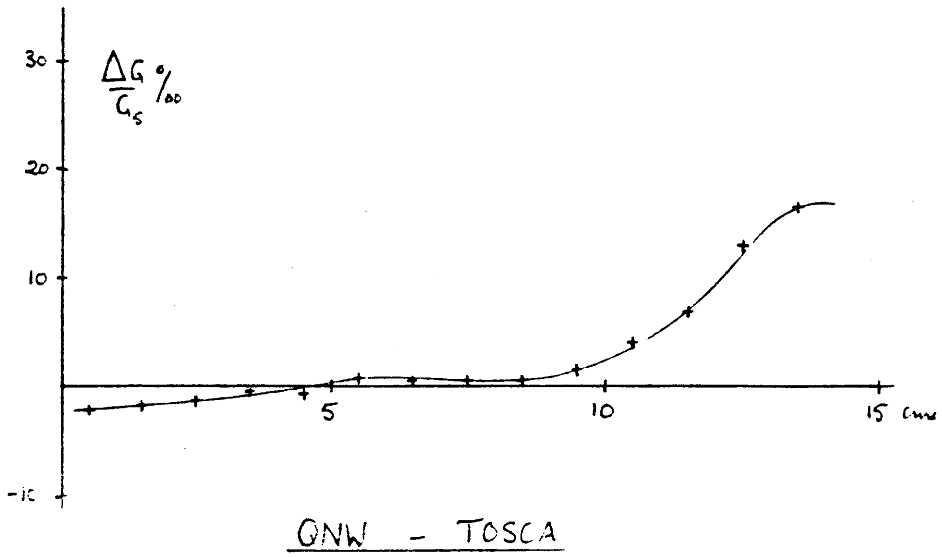


Figure 9