RL-73-060
Internal Report
NIMROD/INJECTOR/31

70 MeV INJECTOR

EFFECTIVE LENGTHS OF DRIFT TUBE DC QUADRUPOLES

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1. GENERAL

By advancing a Hall probe at a fixed radius in 5 mm steps through the bore of a typical tank 2/3 drift tube quadrupole, curves like those of Figure 1 were constructed; magnets were energised at currents ranging from 2.5 to 27A.

Up to about 15A, the effects of saturation are not particularly noticeable; thereafter, the scarcity of iron in the overhanging poletip ends becomes significant, as does the suppression of the B vs. i curve (Figure 2). Under normal circumstances, where currents will be in the range 5 to 10A (gradients approximately 4 - 8 T/m), saturation does not represent a problem. Where matching requirements have demanded high strengths at the first two Tank 2 magnets, a careful examination of the implications revealed that the second could just cope both thermally and magnetically, whilst the first, a half drift tube quadrupole, required a redesign on both these scores[1].

In deciding how best to present effective lengths of quadrupoles, where it is conventional to talk in terms of gradient, k, rather than field, B, and also in terms of strength, $k\ell$, (where ℓ should be the effective length in question) the immediate difficulty is how to extract this parameter from simple measurements made without a beam. For this application, it was decided that a B-plot is equivalent to a k-plot, axially-speaking, so that the effective lengths readily deduced from Figure 1 may simultaneously be interpreted as the effective length required for a statement of quadrupole strength.

To justify this assumption, a family of radial field plots - Figure 3 - at various axial positions was examined for linearity. It can be seen that each plot, even in the poletip overhang region, is sufficiently straight (certainly over the 'working' radial plus and minus 1 cm) to warrant the assumption that k is spatially constant. A measurement of B at 1 cm is therefore also a measure of k out to 1 cm.

2. AXIAL B-PLOTS

Two simple procedures have been adopted to produce curves like those of Figure 1. The first, and more elegant, involved the use of a Hall plate set in a long cylindrical rod snugly fitting the drift-tube bore, and always pressed against the inner diameter above the probe by sprung balls set diametrically opposite this line, and on either side of the probe - see Figure 4(a). A consistent set of axial field values was collected by looking for a maximum at each axial position for the 45° azimuth, and a minimum for the 0° azimuth. It was possible to adjust the probe position, radially, to check that effective lengths were not significantly dependent on radius. In the first instance, this apparatus was used to measure the locations of magnetic centres [2] in relation to the geometric centres of the Tanks 2/3 quadrupoles.

The second method needed no more than a flat surface on which to mount the magnet (either in or out of its drift-tube), a rule, and a retort stand to carry the Hall probe. After alignment, the probe was advanced through the magnet bore as before, and plots recorded at various radii, azimuths and energising currents. Cooling water flow was always sufficient to allow the magnet(s) to reach equilibrium quite quickly. Figure 4(b) illustrates the procedure, which was also used for the radial plots of Figure 3, and to measure the fields in the Tank 4 prototype quadrupole. Figure 5 shows the B-i curve at a radius of 1 cm and at the magnet centre, whilst Figure 7 is a family of half-axial plots - the Tank 4 quadrupole is longer than typical Tanks 2/3 quadrupole and the Hall probe mount is not long enough to permit a full scan of the former. An adaptation of the equipment first described will be used to find magnetic centres and effective lengths of production Tank 4 quadrupoles.

3. CALCULATION OF EFFECTIVE LENGTH

For each of the axial B-plots, the area under the curve was measured with a planimeter and the effective length expressed as:-

$$L_{eff} = \frac{Area}{B_{plateau}}$$

Most of the points in Figure 8 apply to the 5"-long No. 16 quadrupole of Tank 2, but some 4.5" long half drift tube magnet figures have been included. Although there are quadrupoles of five different lengths, Figure 8 may be expected to apply equally to them all, since the incremental effective length, ΔL_{eff}, has been plotted, and this may be assumed to relate to end-effects which are the same for all magnets.

Tank 4 prototype quadrupole results are plotted in Figure 6.

4. RESULTS AND CONCLUSIONS

It is concluded that, for Tanks 2/3 quadrupoles, the incremental effective length is a constant 1.6 cm up to about 10A, then reducing rapidly with current to zero at 28A. At the operating current of 20 - 22A expected for the redesigned Tank 2 half drift tube quad, it is hoped that the increment will have fallen by no more than 30%.

To a first approximation, it may be assumed that the effective length is not dependent on radius or azimuth, in the working volume of the magnets at least.

The data of Figure 2 has been reorganised in Figure 9 to show the percentage departure from the ideal as saturation is shown up by increasing current. This information should be useful in beam matching and dynamics computations.

Tank 4's prototype quadrupole has been powered to 50% higher currents than will be required, without evidence of saturation or variation in effective length, and it is supposed that all production models should exhibit the same high quality.

5. ACNOWLEDGEMENTS

The data condensed into Figures 1-9 represent many hours of patient measurements by J E Ellis, P S Flower, R Marshall, H J Olive and K Potter, (alphabetical order).

6. REFERENCES

1. R T Elliott 70 MeV Injector, Modifications to Tank 2 Input Half Drift Tube Quadrupole. NIMROD(PD)73-14.

2. H Wicks, R Marshall. Private Communication.

Distribution:

Standard +

N D West
R Carr
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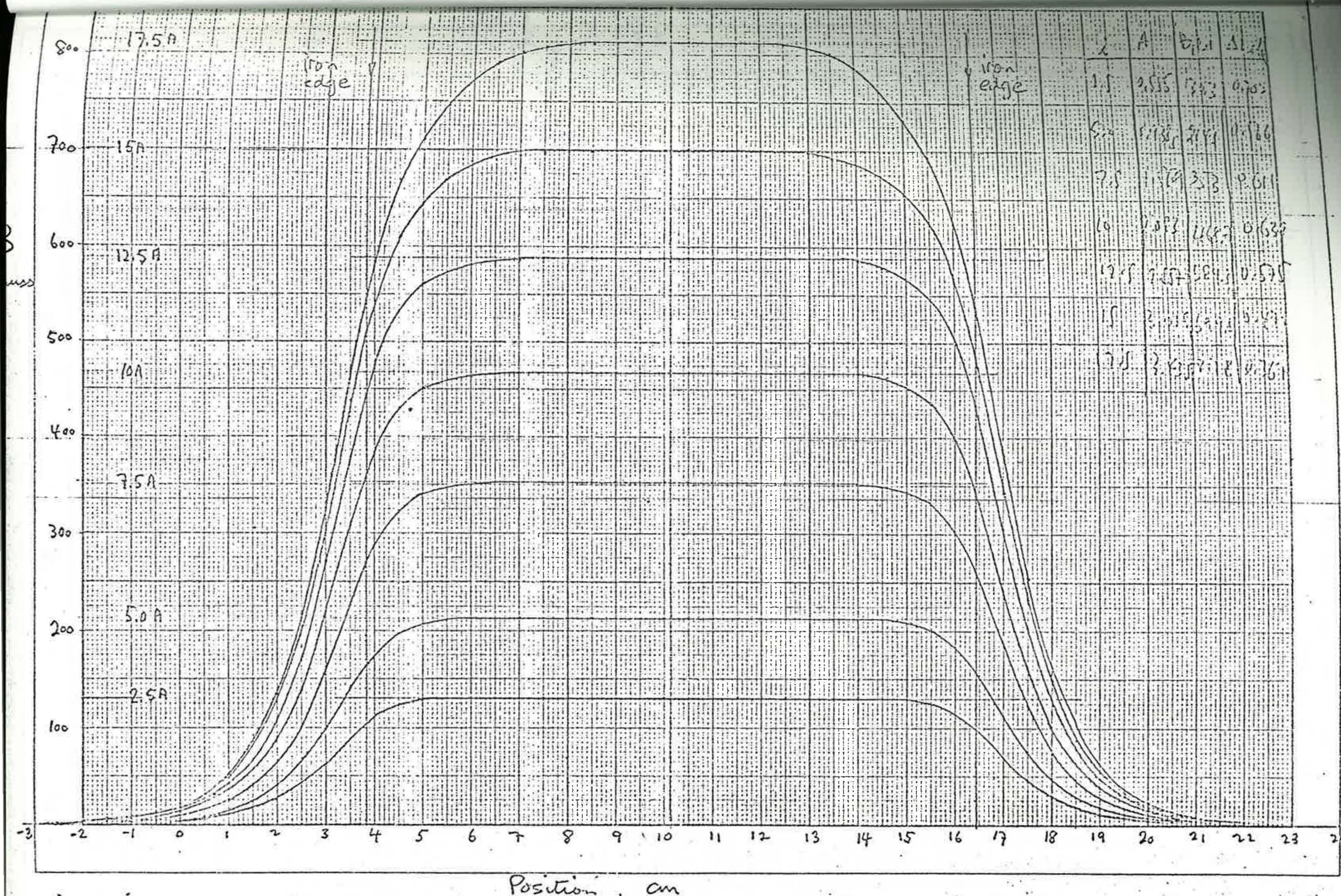
May 1973


17.5A
15A
12.5A
10A
7.5A
5.0A
2.5A
iron edge
iron edge
800
700
600
500
400
300
200
100
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Position, cm

measured at magnet middle

Figure 2 B/k vs i TANK 2

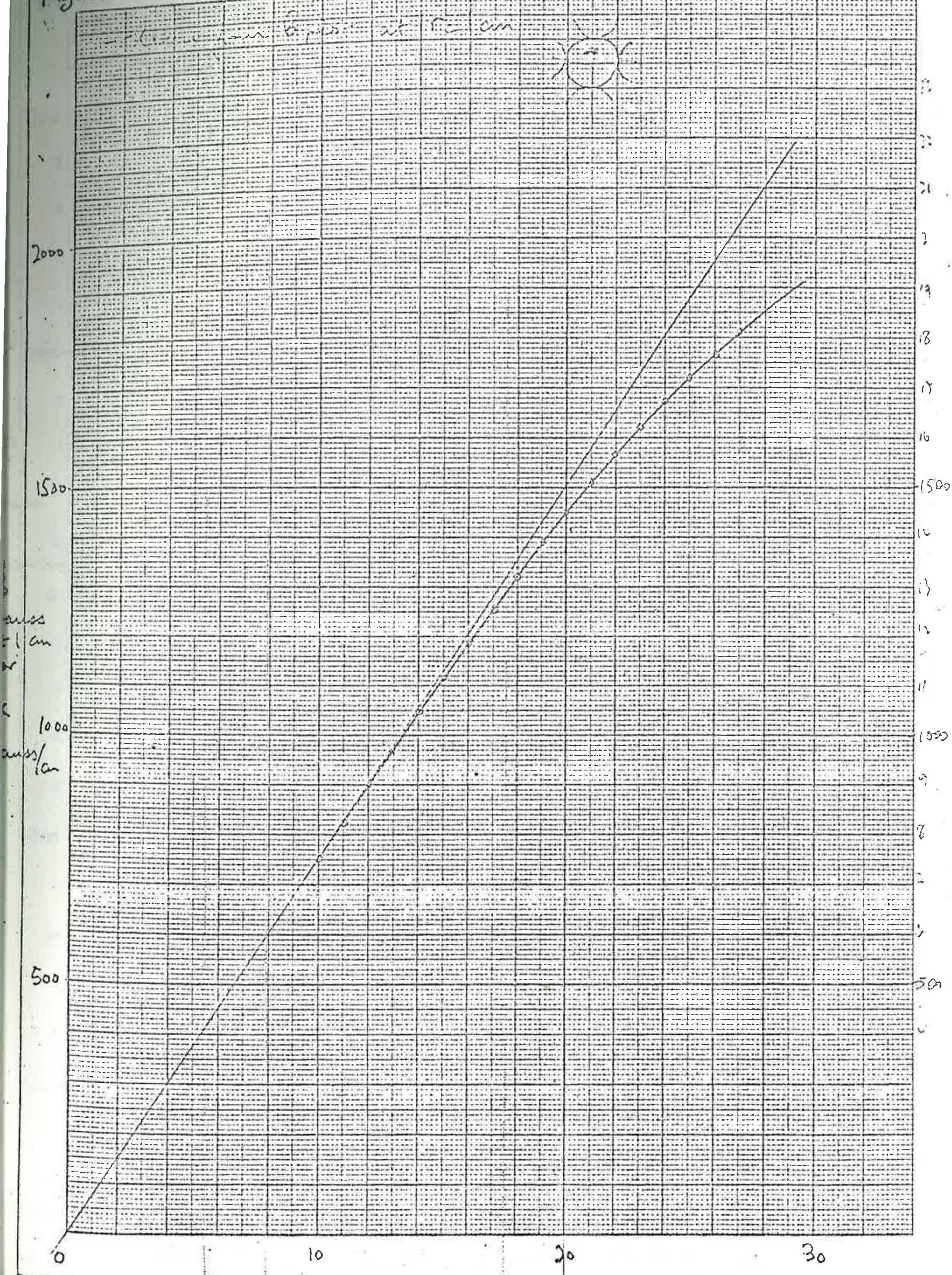
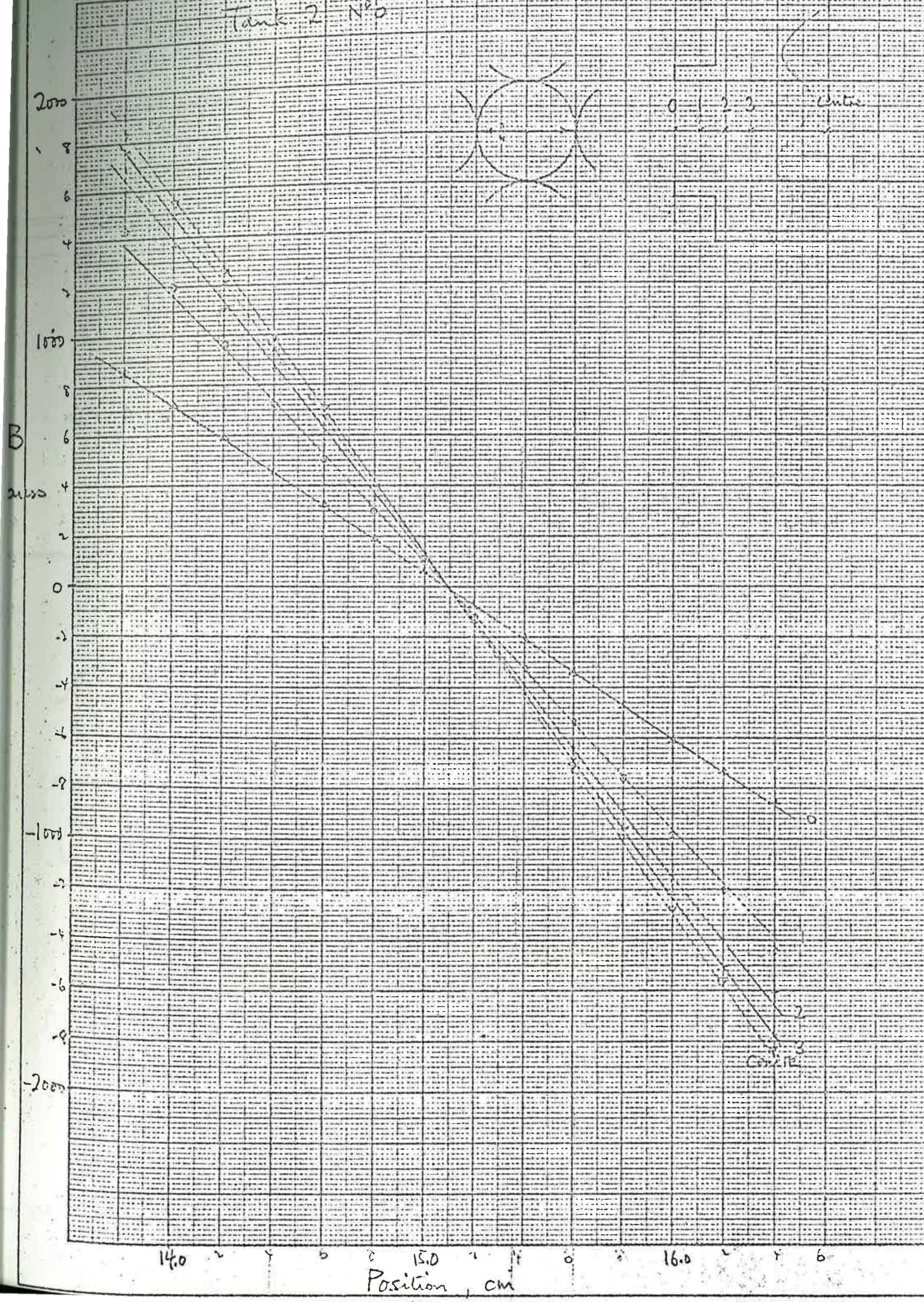
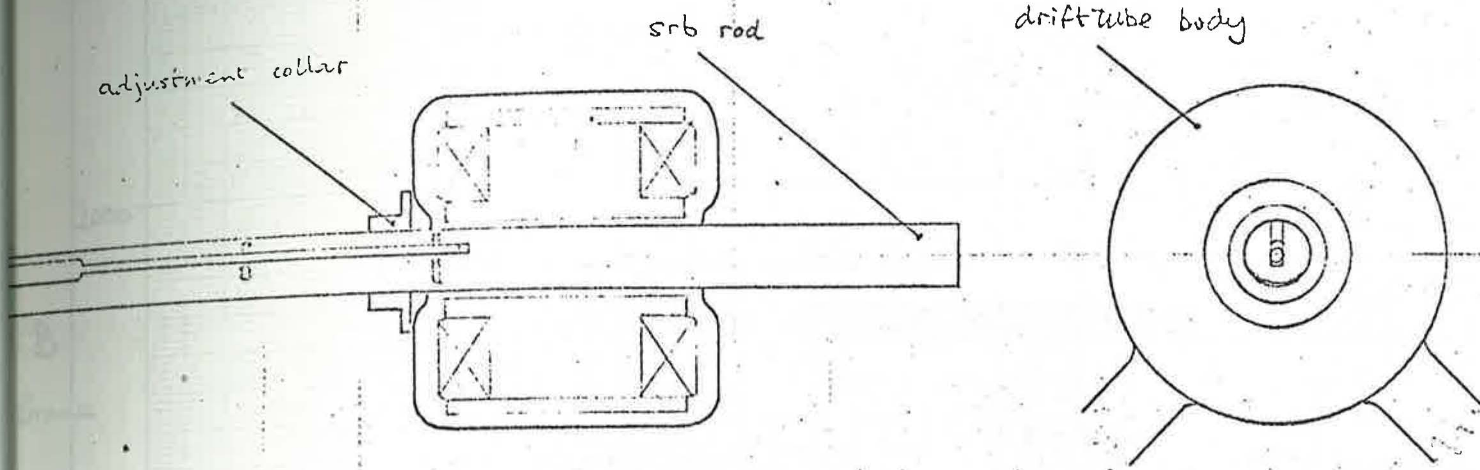
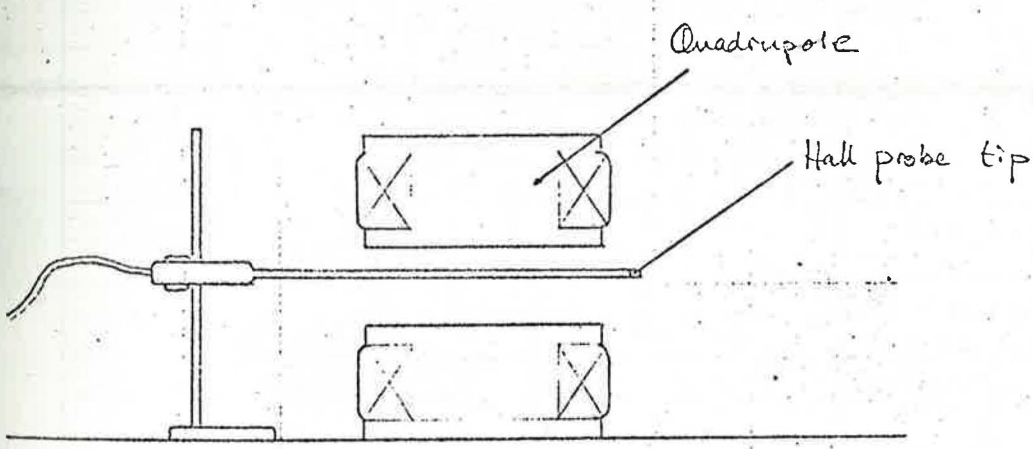


Figure 3 B vs r at various axial positions i = 20A





a) magnetic-centre measuring equipment



b) String and sealing-wax set-up

Figure 4 Apparatus used for constructing B-z plots

Figure 5 B vs i TANK 4 PROTOTYPE QUADRUPOLE

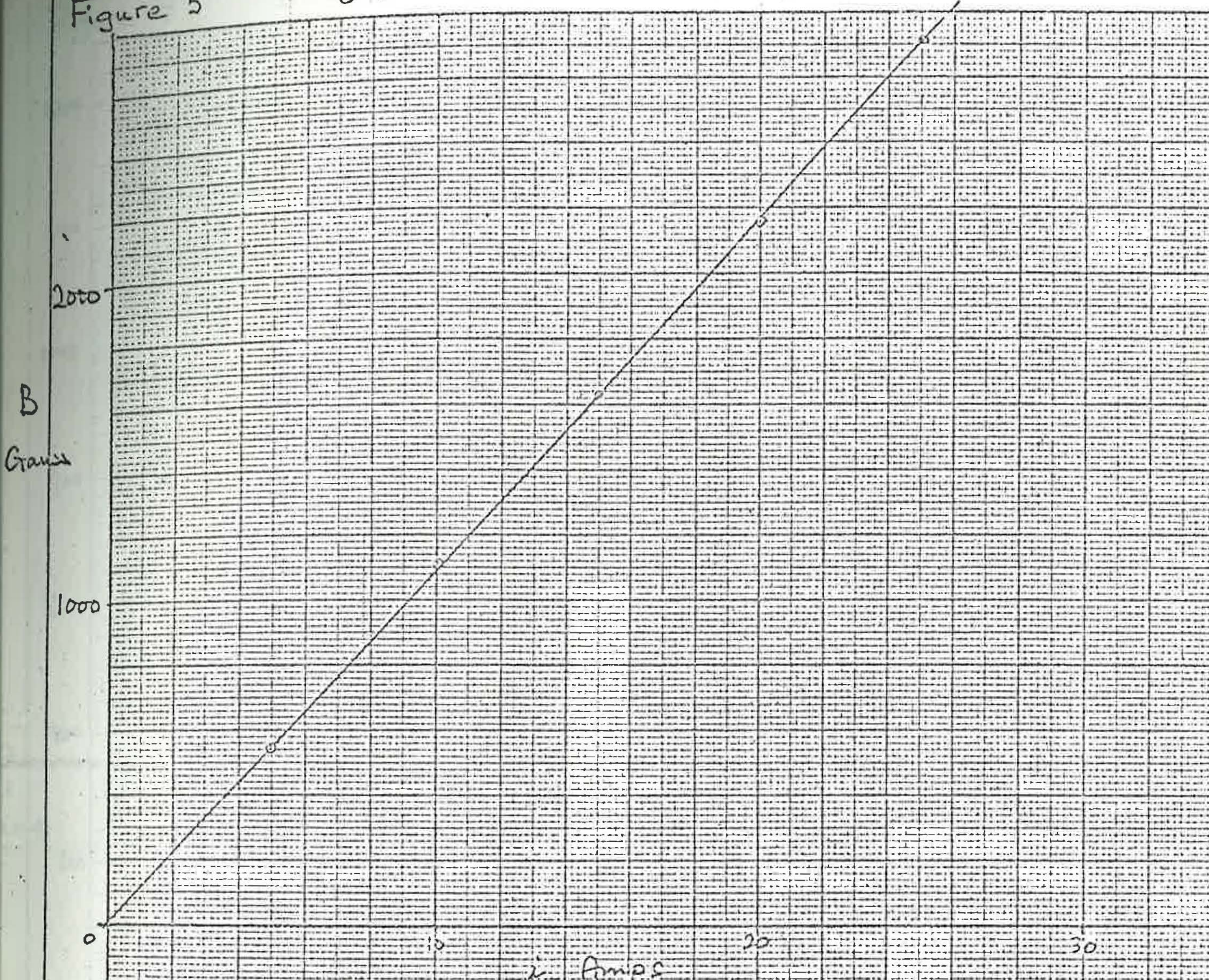
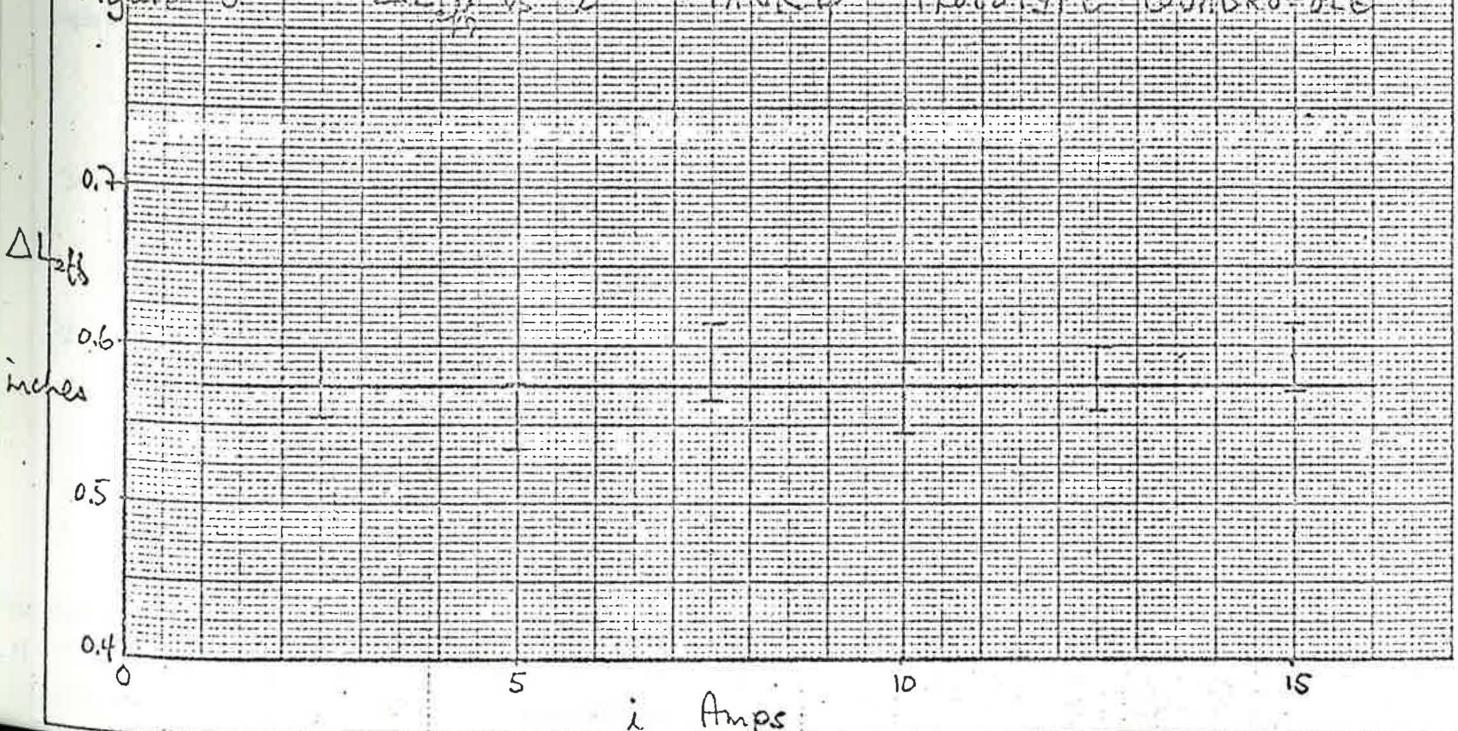


Figure 6 ΔL_{eff} vs i TANK 4 PROTOTYPE QUADRUPOLE



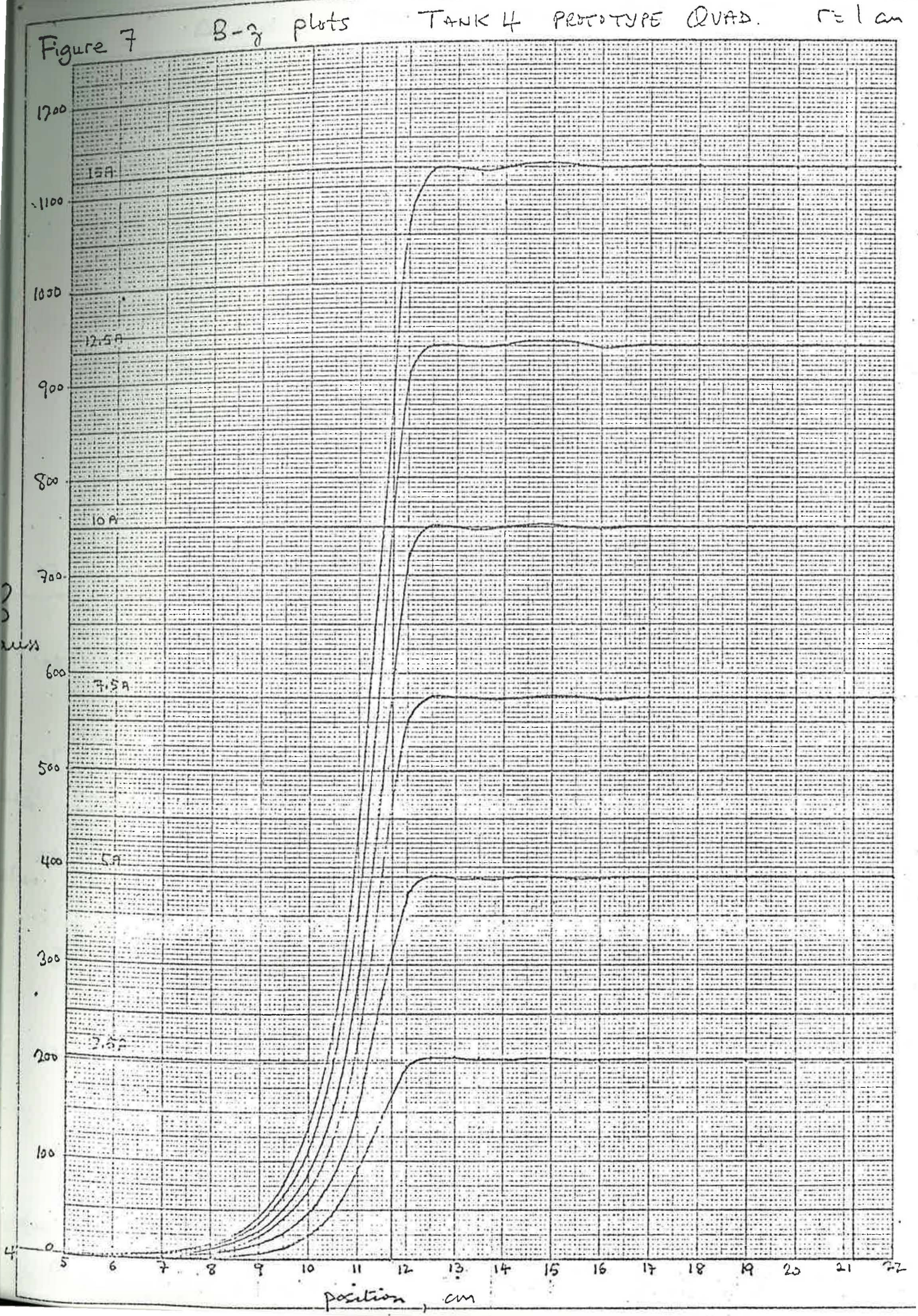
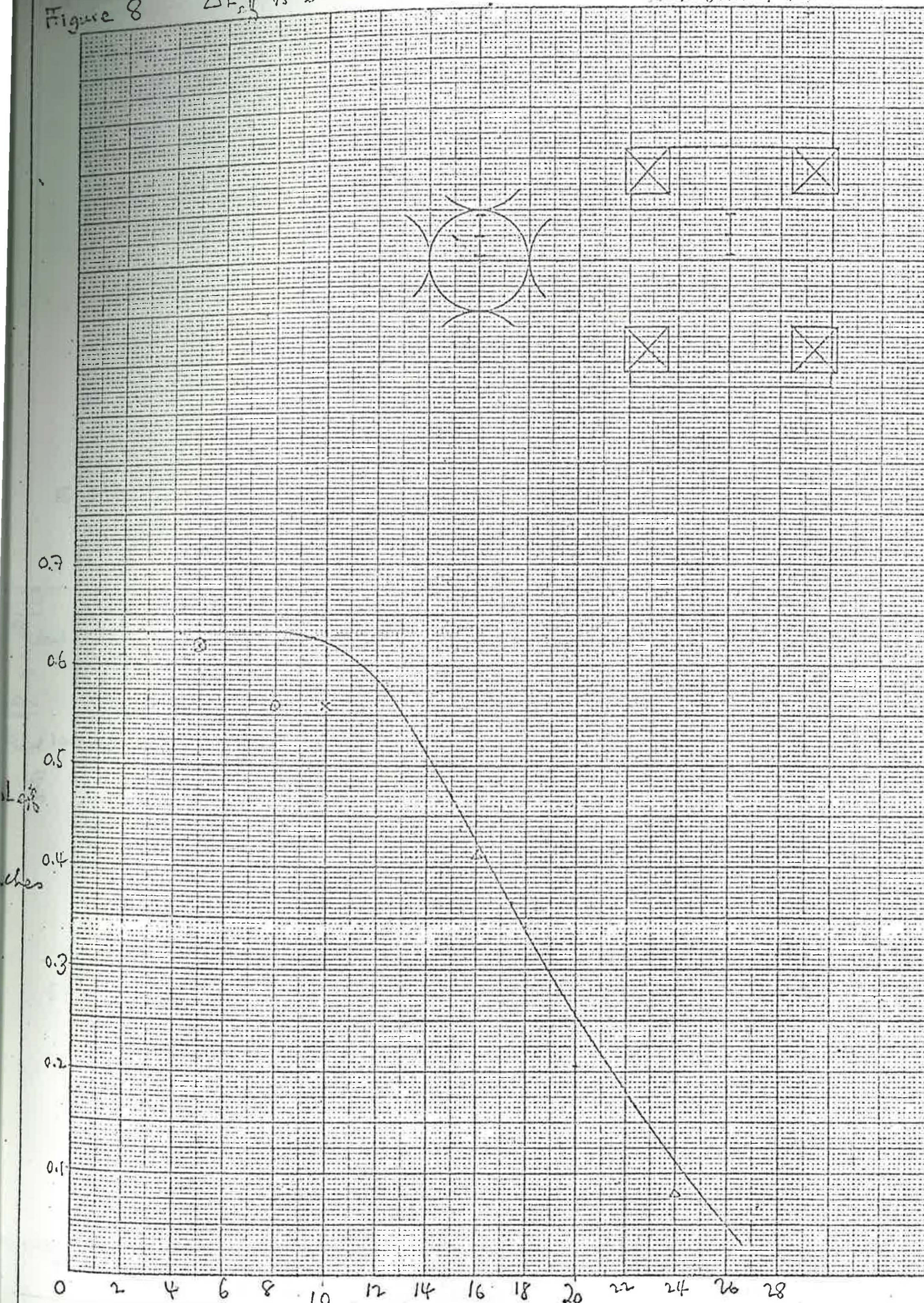


Figure 7
B-z plots TANK 4 PROTOTYPE QUAD. r = 1 cm
15A
12.5A
10A
7.5A
5A
2.5A
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
position, cm

Figure 8 ΔL_{eff} vs i TANK 2 Nos 16 and 0

mostly at r = 1 cm
also r = 0.2 cm, 1.7 cm
and various cylinders



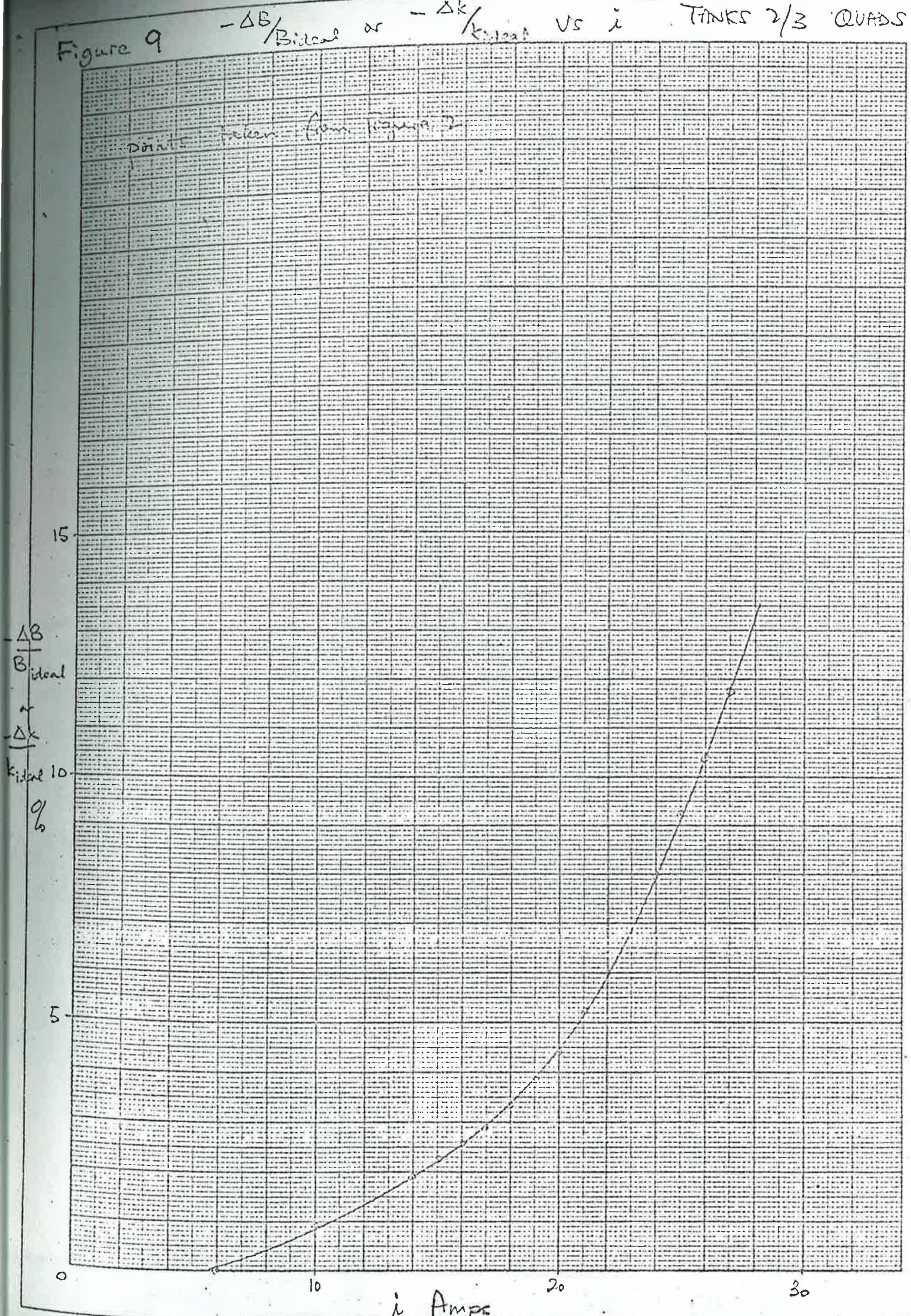


Figure 9 $-\Delta B/B_{ideal}$ or $-\Delta k/k_{ideal}$ vs i TANKS 2/3 QUADS
points taken from Figure 2
$-\Delta B/B_{ideal}$ or $-\Delta k/k_{ideal}$ %
15
10
5
0
10
20
30
i Amps