Hysteresis measurements of Q35 Quadrupoles.

P. S. Flower

Introduction

The basic arrangement of the system is described in "Basic Tests on Quadrupoles to establish polarities".
After field verses current measurements were taken for the first two quadruples, more detailed hysteresis measurements were taken of the subsequent four.

For hysteresis measurements, the hall probe was taped to the centre of quadrant 2, See Fig. 1.

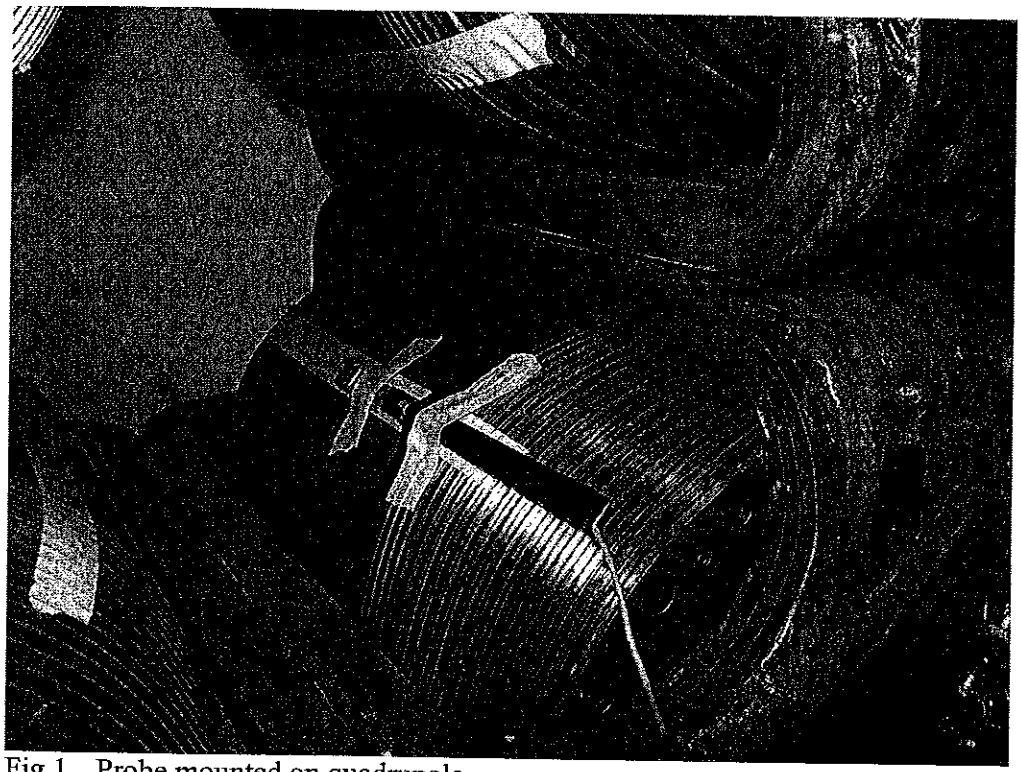


Fig.1 Probe mounted on quadrupole.

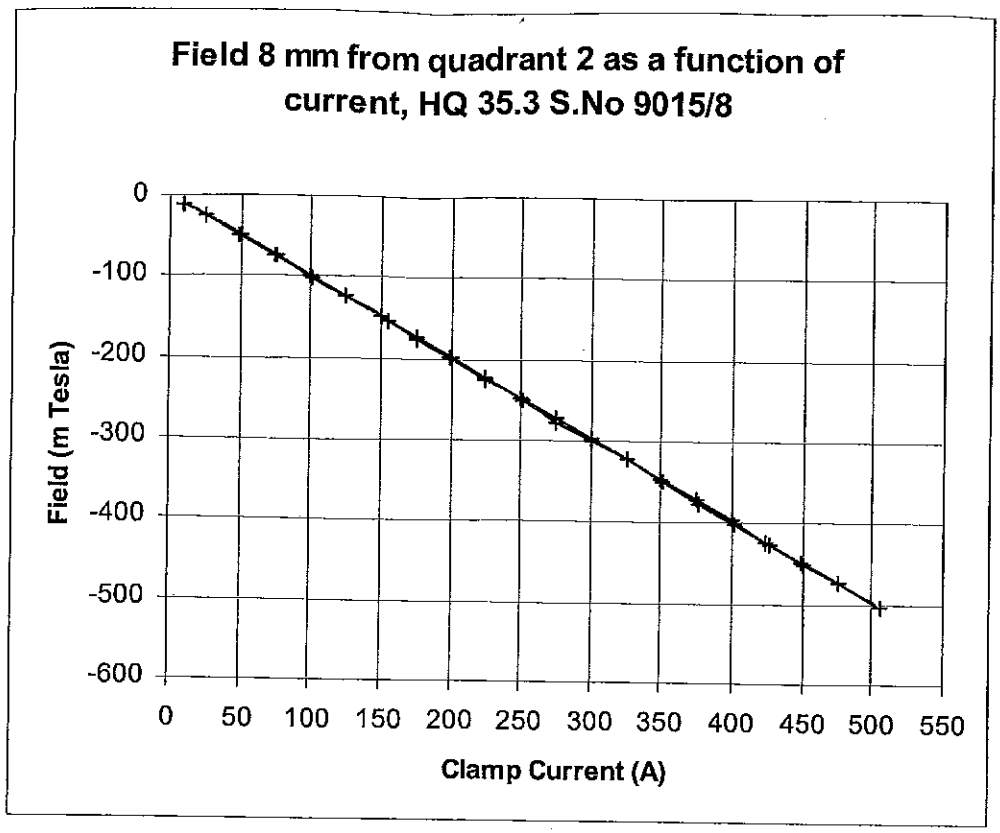
The water flow in the magnets was 60 L/min and the peak current was 500 A.
Initially current measurements were made using a clamp meter. This was found to be inconsistent and so a shunt meter was used. Whilst consistent, it was found that more accurate readings of the current could be obtained using the digital setting on the power supply. This was purported to be accurate to a few parts per million.
Care was taken when taking the measurements to ensure that the target currents were not overshot.

The power was connected with +ve to the front conductor in quadrant 2 except for quadrupole 9015-5.

Results

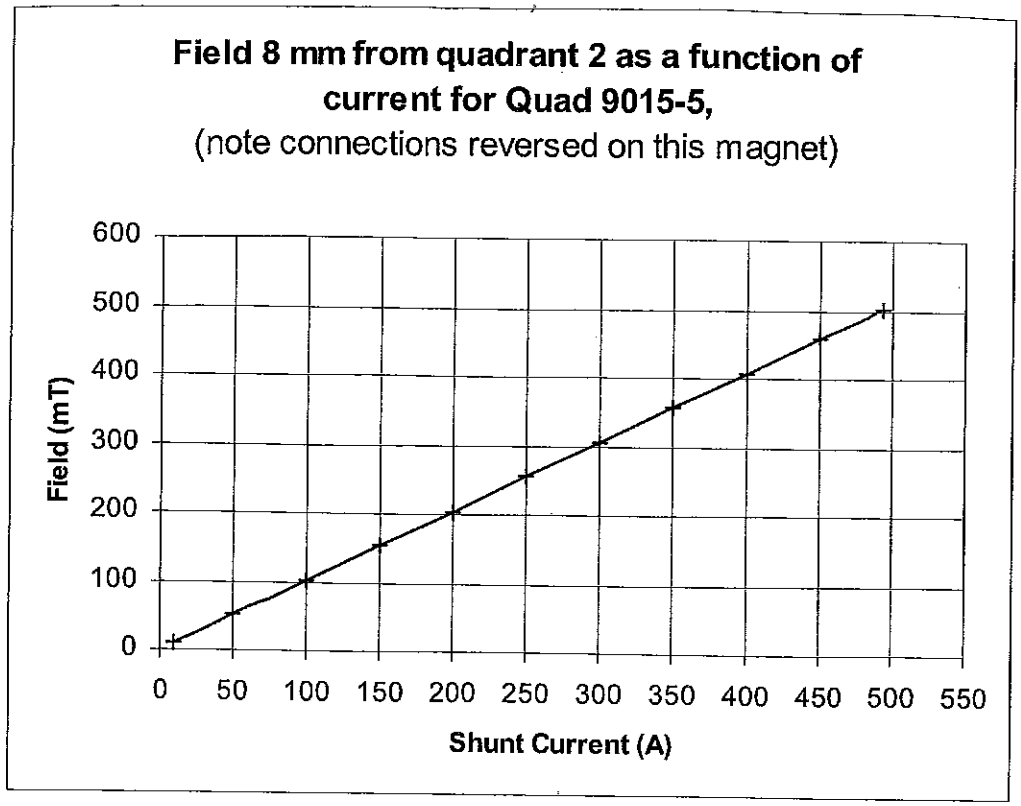
Current (A)	Field (mT)
0	0
10.12	-10.01
24.99	-24.76
50.1	-49.8
75.2	-74.6
99.8	-98.7
125.2	-123.8
149.9	-148.4
175.1	-173.4
200.7	-198.4
225	-222.5
249.9	-247
274.9	-271.7
299.8	-296.2
325.3	-323
350	-347
374.8	-372
399.9	-396
424	-424
449	-449
475	-473
505	-503
476	-474
451	-451
426	-426
402	-402
376	-377
350.8	-349
325.1	-323
300	-299
274.6	-279
250.9	-250
224.7	-225
199.6	-198.1
175	-175.7
155.3	-154.3
124.2	-123.5
101.5	-101
74.2	-74.1
48.3	-48.3
25.3	-25.3
10	-10.2

Data for Quad S.No. 9015/8


Field 8 mm from quadrant 2 as a function of current, HQ 35.3 S.No 9015/8
Field (m Tesla)
0
-100
-200
-300
-400
-500
-600
0
50
100
150
200
250
300
350
400
450
500
550
Clamp Current (A)

Current Shunt (A)	Current Clamp meter (A)	Voltage across coil (V)	Field (mT)
0			
10	10.13	1.49	10.67
50	51.5	7.63	51.8
100	102.5	15.17	102.1
150	153.8	22.76	153.1
200	205.4	30.42	204.3
250	257	38.12	255.3
300	308.5	45.84	305
350	360.9	53.72	356
400	408	61.5	407
450	460	69.5	458
494	505	76.72	503
450	460	69.98	459
400	409	62.05	407
350	361	54.2	357
300	309.4	46.28	306
250	257.8	38.42	255
200	206.4	30.67	204
150	154.7	22.91	154.2
100	103.3	15.28	103.2
50	51.9	7.65	52.3
10	10.78	1.56	11.47

Data for Quod S.No. 9015-5

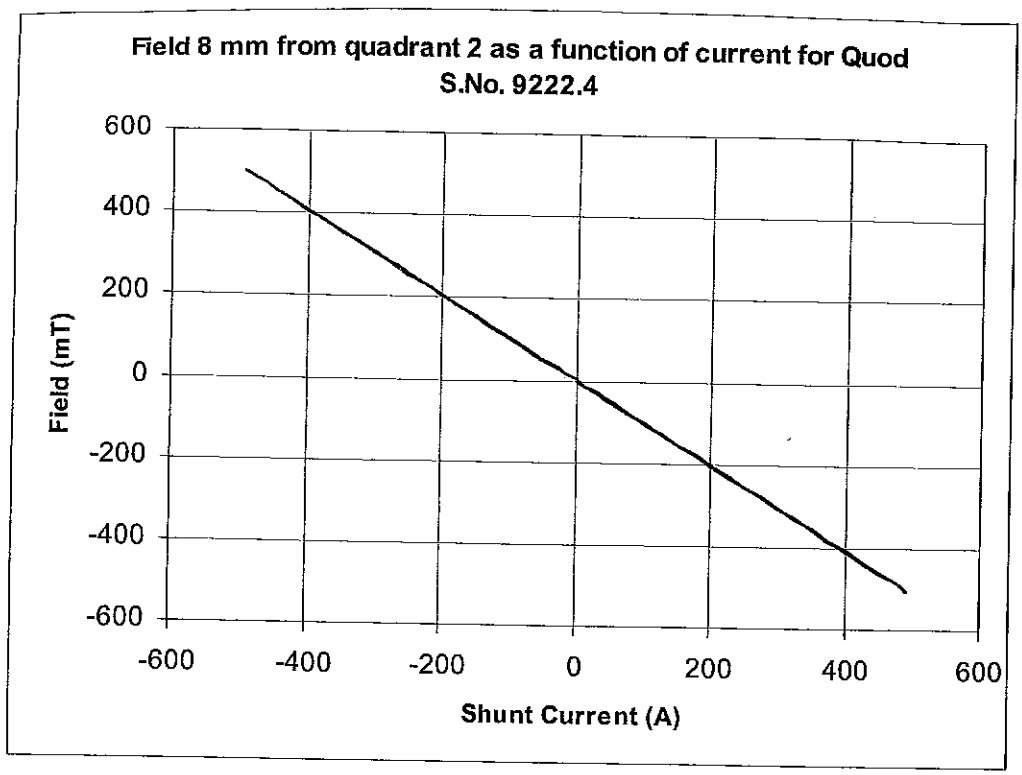

Field 8 mm from quadrant 2 as a function of current for Quad 9015-5,
(note connections reversed on this magnet)
Field (mT)
600
500
400
300
200
100
0
0
50
100
150
200
250
300
350
400
450
500
550
Shunt Current (A)

Clamp Current (A)	Shunt Current (A)	Drive Volts	Field (mT),
0	0	0	-0.04
13.33	13	5.85	-13.36
29.7	29	8.56	-29.6
55.9	55	11	-55.5
56.2	55		-55.5
82.6	80	12.32	-81.6
107	104	15.93	-105.6
132.5	129	19.75	-131
157.8	153	23.5	-156
184.3	179	27.48	-182.2
209.4	203	31.24	-207.1
234.2	227	34.99	-231.6
258.5	250	38.65	-255.6
284.5	276	42.55	-281.1
310.1	300	46.44	-308
335.8	325	50.4	-332
361.5	350	54.3	-359
387.4	375	58.3	-384
410	400	62.2	-409
437	425	66.3	-435
462	450	70.3	-459
487	475	74.4	-485
507	494	77.6	-505
487	474	74.4	-484
462	450	70.7	-460
434	423	66.3	-433
409	398	62.3	-408
383	372	58.2	-382
360.6	349	54.4	-359
333.5	323	50.2	-331
308.8	299	46.4	-307
282.7	274	42.4	-281
258.3	250	38.69	-257
233.4	226	34.92	-233
208.3	201	31.11	-208
182.3	176	27.19	-180.7
157.8	153	23.5	-156.5
131.6	127	19.57	-130.5
107	103	15.9	-106
80.8	78	11.99	-80.1
53.6	52	7.93	-53.2
27.73	27	4.1	-27.6
12.11	12	1.78	-12.31
0.11	0	0	-0.43
0	0	0	0.37
-13.43	-13	-2.02	13
-29.32	-29	-4.48	29.41
-53.7	-54	-8.29	54.7
-80.2	-80	-12.3	81.5
-105.2	-105	-16.13	106.9
-129.6	-129	-19.86	131.8
-153.9	-153	-23.6	156.6
-179.7	-179	-27.56	182.8
-203.8	-203	-31.27	207.2
-229.6	-229	-35.25	233.5
-252.8	-252	-38.85	257
-278.6	-277	-42.85	283.1
-303.2	-301	-46.63	307
-328.6	-326	-50.6	332
-354.4	-352	-54.6	358
-378.4	-375	-58.4	382
-401	-401	-62.4	407
-428	-426	-66.5	434
-451	-450	-70.3	458
-477	-475	-74.5	484
-497	-494	-77.6	503

Data for Quad S.No. 9222.4

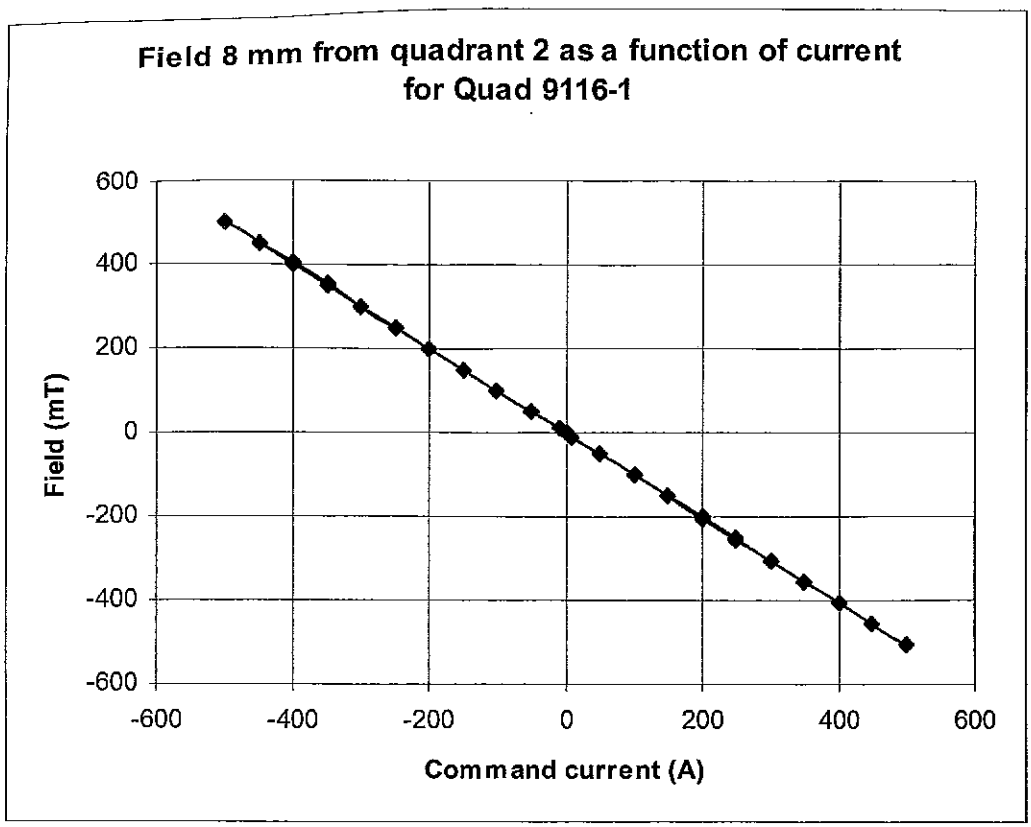
Clamp Current (A)	Shunt Current (A)	Drive Volts	Field (mT),
-476	-474	-74.5	483
-451	-449	-70.6	458
-426	-424	-66.5	433
-400	-399	-62.4	407
-375	-373	-58.3	381
-352.9	-348	-54.3	356
-326.6	-322	-50.1	329
-302.5	-299	-46.4	305
-276.3	-273	-42.3	278
-252.4	-249	-38.58	254
-227.5	-224	-34.7	229
-203.6	-201	-31.01	205
-178.4	-176	-27.12	180.9
-153.6	-151	-23.3	155.7
-128	-126	-19.4	129.9
-103.7	-102	-15.7	105.3
-77.7	-76	-11.74	79.1
-52.6	-51	-7.92	53.7
-27.33	-26	-4.04	27.9
-11.61	-11	-1.65	12
-0.61	0	0	0.935
0	0	0	0.99
12.05	13	2.06	-12.76
26.22	29	4.48	-28.81
49	54	8.35	-54.6
72.2	80	12.3	-80.8
93.8	104	15.98	-105.3
116.5	129	19.87	-131.1
138.8	154	23.68	-156.5
161.2	179	27.53	-181.9
184	204	31.42	-207
205	227	35.05	-231.4
227.4	252	38.92	-256.8
249.4	276	42.75	-281.6
271.4	301	46.57	-309
294.3	326	50.6	-334
316.8	351	54.5	-359
338.7	375	58.4	-384
361.7	401	62.5	-410
384.3	426	66.5	-435
405	451	70.6	-460
428	476	74.6	-486
444	494	77.7	-504
427	475	74.6	-485
405	451	70.8	-460
381	424	66.6	-434
361.5	399	62.5	-409
338.1	373	58.4	-382
315.8	349	54.4	-358
292.3	323	50.2	-331
270.1	298	46.4	-306
247.6	273	42.4	-281
225.7	249	38.59	-257
202.7	224	34.6	-230
182.4	201	31.06	-207
159.9	176	27.19	-180.5
137.8	152	23.4	-155.5
114.7	126	19.44	-129.5
93	102	15.72	-104.7
69.7	76	11.76	-78.5
46.3	51	7.77	-52
24.19	26	4.02	-27.1
10.75	11	1.75	-12.05
0.43	0	0	-0.4

Data for Quad S.No. 9222.4 continued


Field 8 mm from quadrant 2 as a function of current for Quod S.No. 9222.4
600
400
200
0
-200
-400
-600
Field (mT)
-600
-400
-200
0
200
400
600
Shunt Current (A)

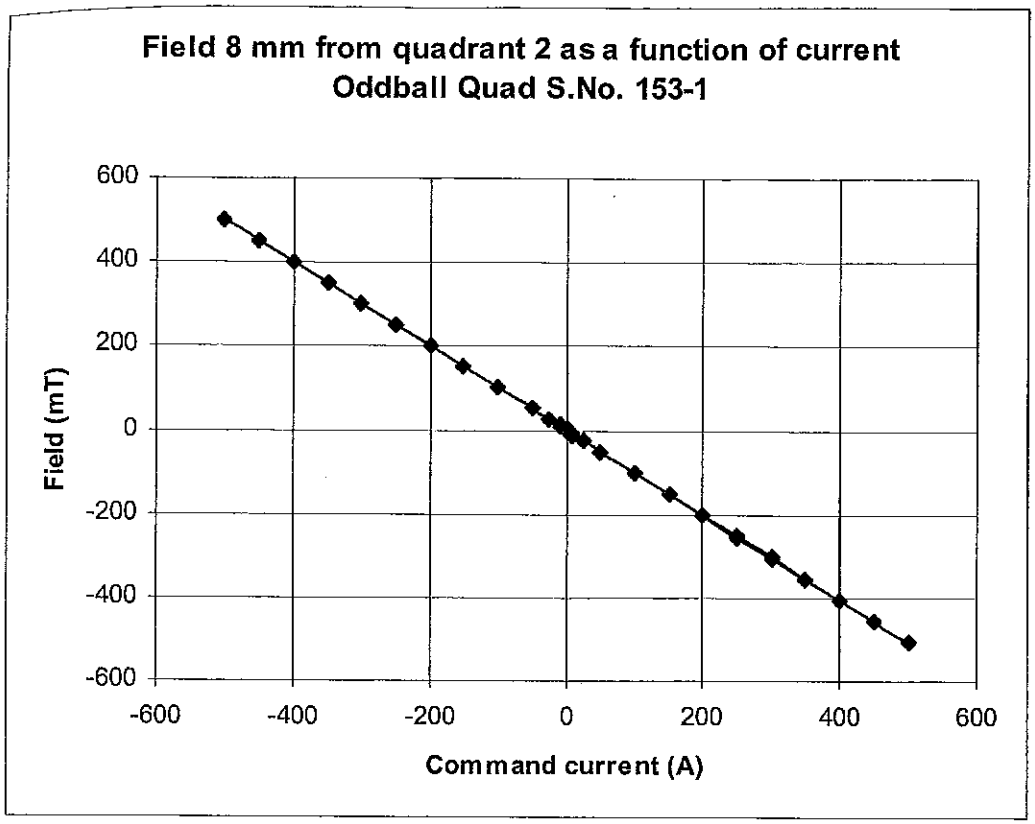
Target current	Shunt (A)	Clamp (A)	Field (mT)	Volts (V)
0	0	0.57	-0.409	
10	10.9	11.37	-11.5	
50	50.3	50.4	-51.3	
100	99.6	99.6	-101.4	
150	149	148.9	-151.9	
200	198.3	198.1	-202.2	
250	247.7	247.4	-252.6	
300	297	296.7	-304	
350	346.4	346.1	-354	
400	395.8	395.3	-405	
450	445.1	442	-454	
500	494.4	491	-503	
450	445.2	443	-455	
400	395.9	494	-405	
350	346.5	346.8	-355	
300	297.1	297.5	-304	
250	247.8	248.2	-255	
200	198.4	198.8	-204	
150	149.1	149.5	-152.7	
100	99.7	100.1	-102.1	
50	50.3	50.6	-51.9	
10	10.9	11.56	-11.8	
0	0	0.62	-0.7	
0	0	-0.42	-0.565	
-10	-10.8	-10.99	10.42	
-50	-50.1	-49.9	50.5	
-100	-99.5	-99	100.9	-15.32
-150	-149	-148.1	151.4	-22.92
-200	-198.3	-197.2	201.7	-30.54
-250	-247.7	-246.3	252.1	-28.21
-300	-297	-295.5	301	-45.9
-350	-346.4	-344.6	351	-53.69
-400	-395.7	-393.7	402	-61.52
-450	-445.1	-440	451	-69.39
-500	-494.4	-489	501	-77.44
-450	-445.2	-441	452	-69.74
-400	-395.8	-392	403	-61.89
-350	-346.5	-345.1	353	-54
-300	-297.1	-296.1	302	-46.2
-250	-247.8	-247	252	-38.45
-200	-198.4	-198	202	-30.7
-150	-149	-148.8	152	-23.02
-100	-99.6	-99.7	102.3	-15.36
-50	-50.3	-50.5	52	-7.75
-10	-10.9	-11.47	11.9	-1.67
0	0	-0.56	0.651	0
0	0	0	0.57	0
10	10.9	11.26	-10.4	1.65
50	50.2	50.3	-50.4	7.71
100	99.6	99.3	-100.7	15.31
150	149	148.5	-151.2	22.91
200	198.3	197.6	-201.5	30.54
250	247.7	246.8	-251.8	38.2
300	297	296	-304	45.8
350	346.3	345.1	-353	53.67
400	395.7	394.3	-404	61.47
450	445	442	-454	69.35
500	494.4	490	-503	77.39
450	445.1	442	-454	69.76
400	395.8	393	-405	61.87
350	346.4	345.6	-354	54
300	297.1	296.4	-304	46.18
250	247.8	247.4	-254	38.42
200	198.3	198.2	-204	30.68
150	149	149.1	-152.3	23
100	99.6	99.8	-101.9	15.35
50	50.3	50.6	-51.7	7.74
10	10.9	11.47	-11.6	1.7
0	0	0	-0.7	0

Data for Quad S.No. 9116.1


Field 8 mm from quadrant 2 as a function of current for Quad 9116-1
600
400
200
0
-200
-400
-600
Field (mT)
-600
-400
-200
0
200
400
600
Command current (A)

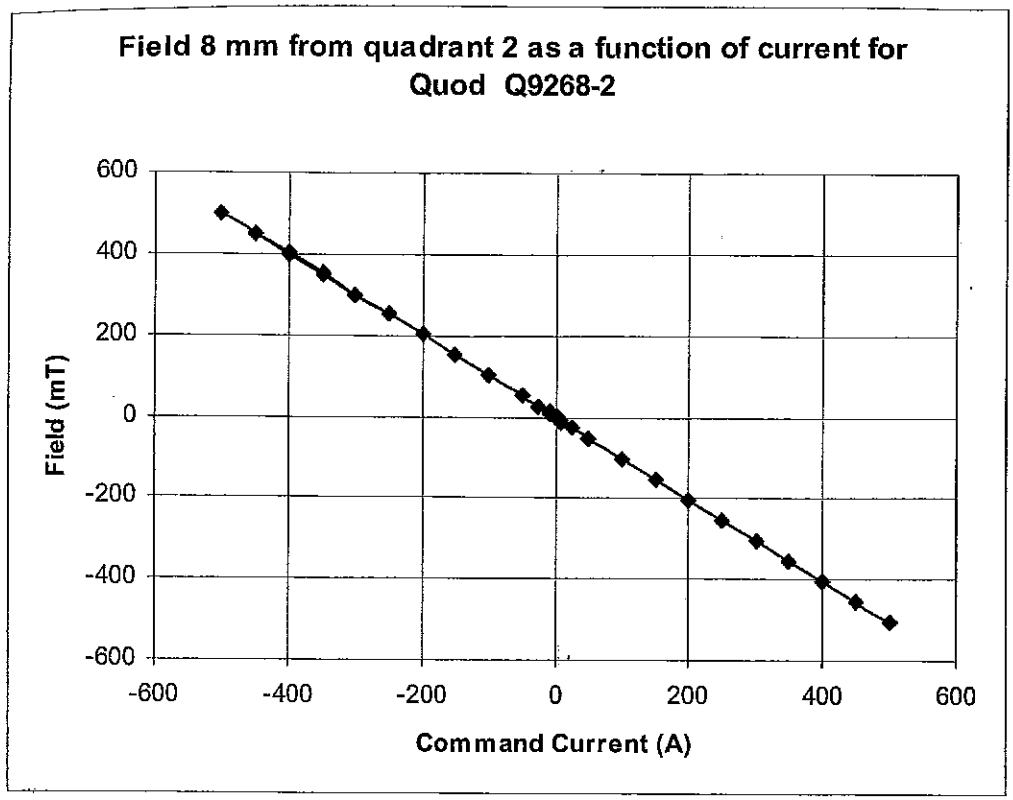
current	clamp	shunt	volts	field
0	0.27	0	0.001	-0.322
10	11.39	10.9	1.7	-11.38
25	26.54	25.6	3.98	-26.42
50	51.2	50.3	7.8	-51.4
100	101.6	99.6	15.46	-101.5
150	152.1	149	23.14	-152
200	202.5	198.3	30.84	-202.4
250	253.2	247.7	38.6	-252.7
300	303.6	297	46.35	-304
350	354.2	346.3	54.2	-354
400	402	398.7	62.2	-405
450	453	445.1	70.2	-455
500	503	494.4	78.3	-505
450	453	445.1	70.7	-455
400	403	395.8	62.8	-405
350	354.9	346.4	54.8	-356
300	304.3	297.1	46.9	-305
250	253.9	247.8	39	-255
200	203.3	198.4	31.15	-204
150	152.8	149	23.35	-152.7
100	102.1	99.6	15.58	-102.1
50	51.5	50.3	7.83	-51.9
25	26.77	25.6	3.99	-26.7
10	11.54	10.9	1.69	-11.71
0	0.36	0	0	-0.53
0	-0.34	0	0	-0.48
-10	-11.3	-10.7	-1.63	10.44
-25	-26.4	-25.6	-3.96	25.54
-50	-51.2	-50.3	-7.8	50.7
-100	-101.6	-99.6	-15.44	100.9
-150	-152	-149	-23.12	151.5
-200	-202.4	-198.3	-30.8	201.7
-250	-253.1	-247.7	-38.55	252.1
-300	-303.4	-297	-46.32	301
-350	-353.8	-346.3	-54.1	351
-400	-402	-395.7	-62	402
-450	-452	-445.1	-70	451
-500	-502	-494.4	-78.2	502
-450	-452	-445.1	-70.6	452
-400	-402	-395.8	-62.7	403
-350	-354.5	-346.4	-54.7	352
-300	-304.1	-297.1	-46.8	302
-250	-253.6	-247.8	-38.99	252
-200	-203.1	-198.4	-31.15	201
-150	-152.7	-149	-23.36	152.7
-100	-102.1	-99.7	-15.6	102.2
-50	-51.5	-50.3	-7.85	51.9
-25	-26.25	-25.7	-4	26.7
-10	-11.51	-10.9	-1.7	11.72
0	-0.41	0	0	0.56
0	0.04	0	0	0.46
10	11.01	10.9	1.69	-10.57
25	26.03	25.6	3.97	-25.62
50	50.6	50.3	7.8	-50.7
100	100.5	99.6	15.44	-100.9
150	150.7	149	23.11	-151.3
200	200.7	198.3	30.79	-201.7
250	250.9	247.7	38.5	-252
300	301	297	46.27	-304
350	351	346.3	54.1	-354
400	399	395.7	62	-405
450	449	445.1	70	-455
500	499	494.4	78.2	-504
450	449	445.1	70.6	-455
400	399	395.8	62.7	-405
350	351.6	346.4	54.7	-355
300	301.7	297.1	46.8	-305
250	251.6	247.8	38.97	-255
200	201.5	198.4	31.14	-204
150	151.3	149	23.34	-152.6
100	101.2	99.6	154.57	-102
50	51	50.3	7.85	-51.8
25	26.28	25.7	3.99	-26.6
10	11.22	10.9	1.69	-11.63
0	0.1	0	0	-0.42

Data for Quad S.No. 153.1


Field 8 mm from quadrant 2 as a function of current
Oddball Quad S.No. 153-1
Field (mT)
600
400
200
0
-200
-400
-600
-600
-400
-200
0
200
400
600
Command current (A)

current	clamp	shunt	volts	field
0		0	0	-0.397
10		10.9	1.7	-11.46
25		25.6	3.94	-26.35
50		50.2	7.71	-51.2
100		99.6	15.27	-101.1
150		149	22.85	-151.4
200		198.3	30.44	-201.5
250		247.7	38.07	-251.6
300		297	45.73	-303
350		346.3	53.4	-353
400		395.7	61.2	-403
450		445	69.1	-453
500		494.3	77.1	-503
450		445.1	69.6	-454
400		395.8	61.7	-405
350		346.4	53.9	-355
300		297	46.1	-304
250		247.8	38.33	-254
200		198.3	30.62	-204
150		149	22.96	-152.7
100		99.6	15.32	-102.3
50		50.3	7.73	-52.2
25		25.6	3.94	-27
10		10.9	1.6	-12.08
0		0	0	-0.92
0	-0.04	0	0	-0.75
-10	-11.17	-10.9	-1.64	10.25
-25	-26.5	-25.6	-3.92	25.21
-50	-51.7	-50.3	-7.69	50.3
-100	-102.8	-99.6	-15.2	100.5
-150	-153.8	-149	-22.8	150.9
-200	-204.8	-198.3	-30.39	201.3
-250	-256.1	-247.7	-38.02	251.6
-300	-307.1	-296.9	-45.69	300
-350	-358.1	-346.3	-53.4	351
-400	-407	-395.6	-61.2	401
-450	-457	-445	-69	451
-500	-509	-494.3	-77.1	500
-450	-458	-445.1	-69.5	451
-400	-407	-395.7	-61.7	402
-350	-358.9	-346.4	-53.8	352
-300	-307.8	-297	-46	301
-250	-256.9	-247.7	-38.3	252
-200	-205.8	-198.3	-30.59	201
-150	-154.6	-149	-22.94	152.8
-100	-103.5	-99.6	-15.31	102.3
-50	-52.4	-50.3	-7.72	52.1
-25	-27.12	-25.6	-3.93	27
-10	-11.74	-10.9	-1.67	11.94
0	-0.46	0	0	0.85
10	11.53	10.8	1.67	-10.2
25	26.92	25.6	3.92	-25.31
50	52.1	50.3	7.7	-50.3
100	103	99.6	15.25	-100.5
150	154	149	22.82	-150.9
200	204.9	198.3	30.41	-201
250	256.1	247.7	38.04	-251.4
300	307.1	297	45.72	-303
350	358.1	346.3	53.4	-353.1
400	407	395.7	61.2	-403
450	457	445	69.1	-453
500	508	494.4	77.1	-503
450	458	445.1	69.5	-454
400	407	395.8	61.7	-405
350	358.7	346.4	53.9	-355
300	307.7	297.1	46	-304
250	256.8	247.8	38.3	-254.1
200	205.6	198.3	30.6	-204
150	154.6	149	22.95	-152.3
100	103.5	99.6	15.34	-102.2
50	52.4	50.3	7.72	-52
25	27.14	25.6	3.93	-27
10	11.74	10.9	1.6	-12
0	0.44	0	0	-0.919
0	0.44	0	0	-0.8

Data for Quad S.No. 9268-2



Conclusion

There was very little evidence of significant hysteresis.
Any effect was of the order of 1mT which isof the accuracy of the gaussmeter and measurement system.
There was some indication that the field could take a couple of minutes to settle down after a field change

P.S.Flower
26 March 2008