Fermi National Accelerator Laboratory

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MINOS Test Toroid Magnetic Measurements

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MINOS TEST TOROID MAGNETIC MEASUREMENTS

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ABSTRACT

Magnetic measurements were made on a test ring constructed from the same steel used on the prototype MINOS far detector plate located in NMS. The conventionally used technique of measuring sense coil voltage induced by step changes in excitation current voltage was successful in providing stable, repeatable measurements. Measurements were made at several locations on the steel and the results are presented.

MINOS TEST TOROID MAGNETIC MEASUREMENTS

Measurements were made on a test toroid constructed from MINOS detector steel at a test setup in the Proton Pole Building on Friday, January 15, 1999 and then again on Tuesday, January 26, 1999. The measurements were made using a movable 50 turn sense coil wound of AWG 28 wire. The toroid driving coil was wound with 400 turns of AWG 14 wire. The power supply was a Kepco Bipolar Operational Amplifier Power Supply, Model BOP 15-20M operated in voltage regulate mode. The shunt used to measure the current was a Leeds and Northrup Catalog # 4361, 100 A, 0.01 ohm.

The toroid set up is shown below. All measurements were made using the integrator used in all previous measurements. For a toroid,

$$H = \frac{NI}{l}\text{; } where$$

$$N = number\ of\ turns;\ driving\ coil = 400$$

$$l = 2\pi R;\ where\ R\ is\ the\ mean\ radius = .254m$$

$$also,$$

$$E_0 = \frac{N}{RC}\Delta\Phi$$

$$E_0 = \frac{NS}{RC}B$$

$$B = \frac{RC}{N_S S}E_0; where$$

$$RC = 4.945X10^{-2}$$

$$S = cross\ section\ (m^2) = 9.68X\ 10^{-4}m^2$$

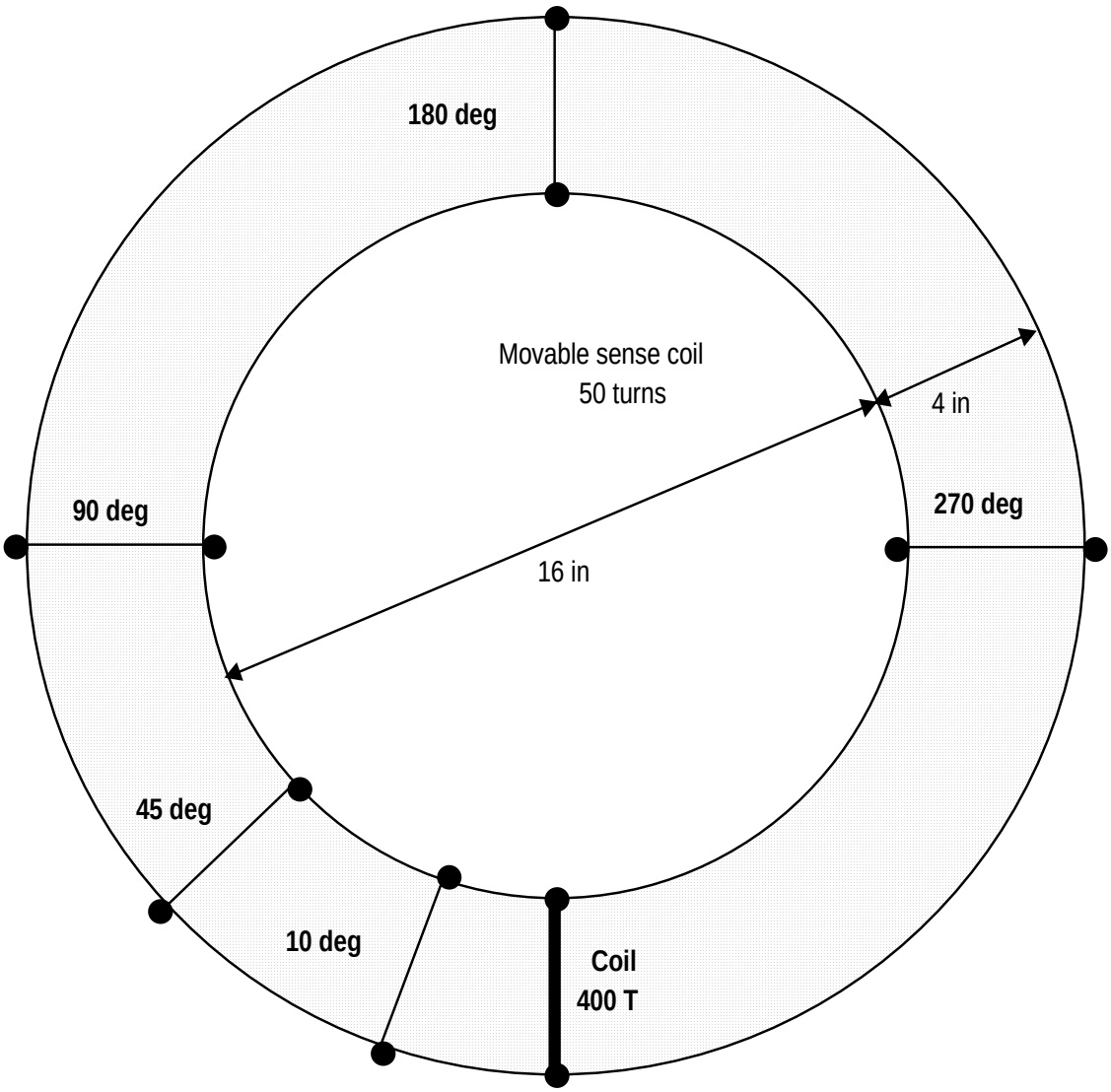
$$N_S = number\ of\ turns;\ sensor = 50$$

$$thus,\ for\ this\ setup:$$

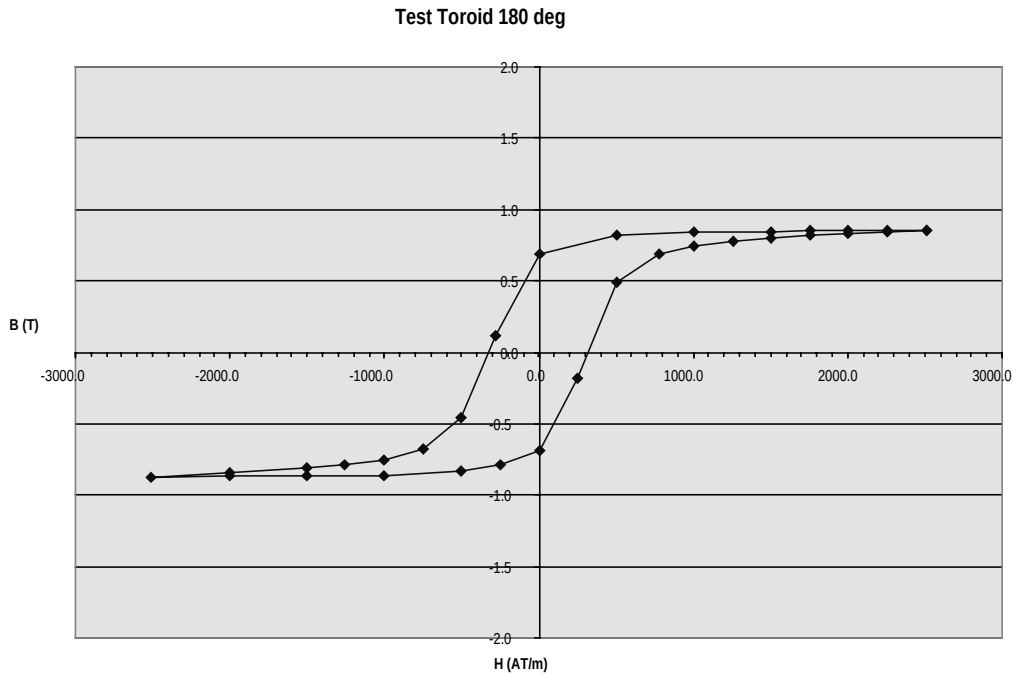
$$H = 250.64I \quad (Aturns/m)$$

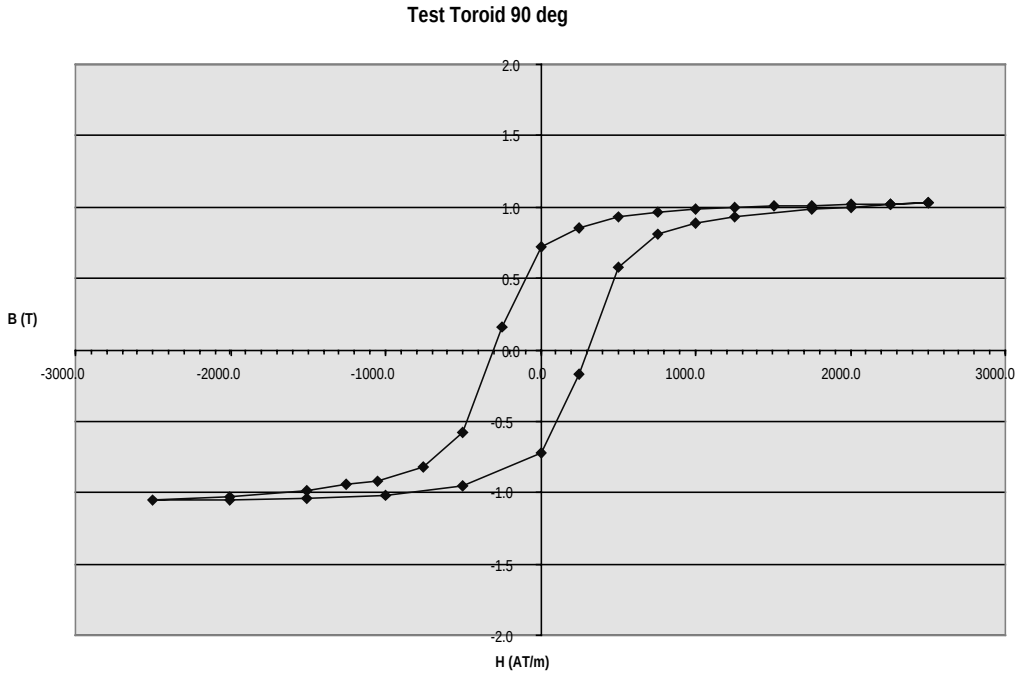
$$B = 1.02E_0 \quad (T)$$

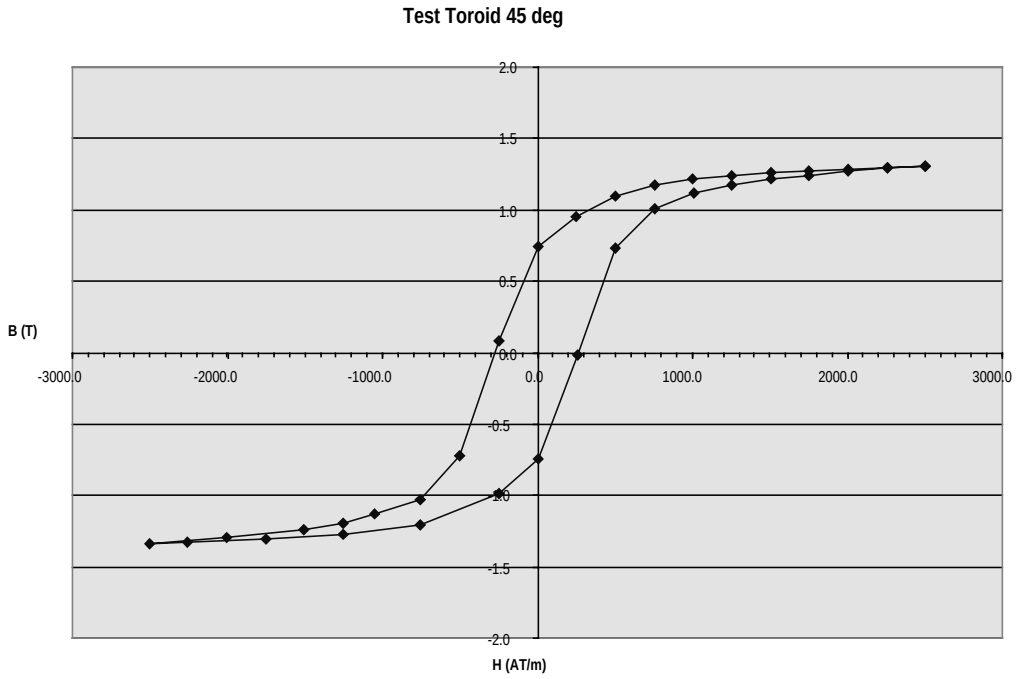
The results of the measurements are presented in two sets; the 1/15 data followed by the 1/26 data. Each set consists of the data plots and a spreadsheet of the raw and adjusted data. Each plot is identified by the position of the sense coil.

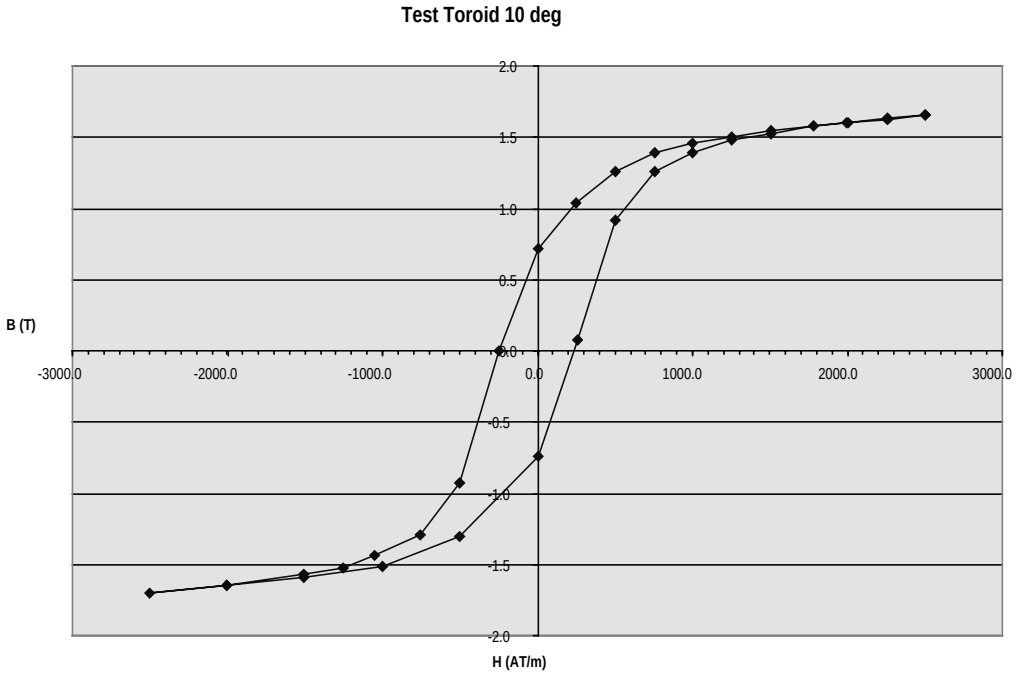


Test Toroid Measurement Setup


Test Toroid 180 deg
B (T)
H (AT/m)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-3000.0
-2000.0
-1000.0
0.0
1000.0
2000.0
3000.0

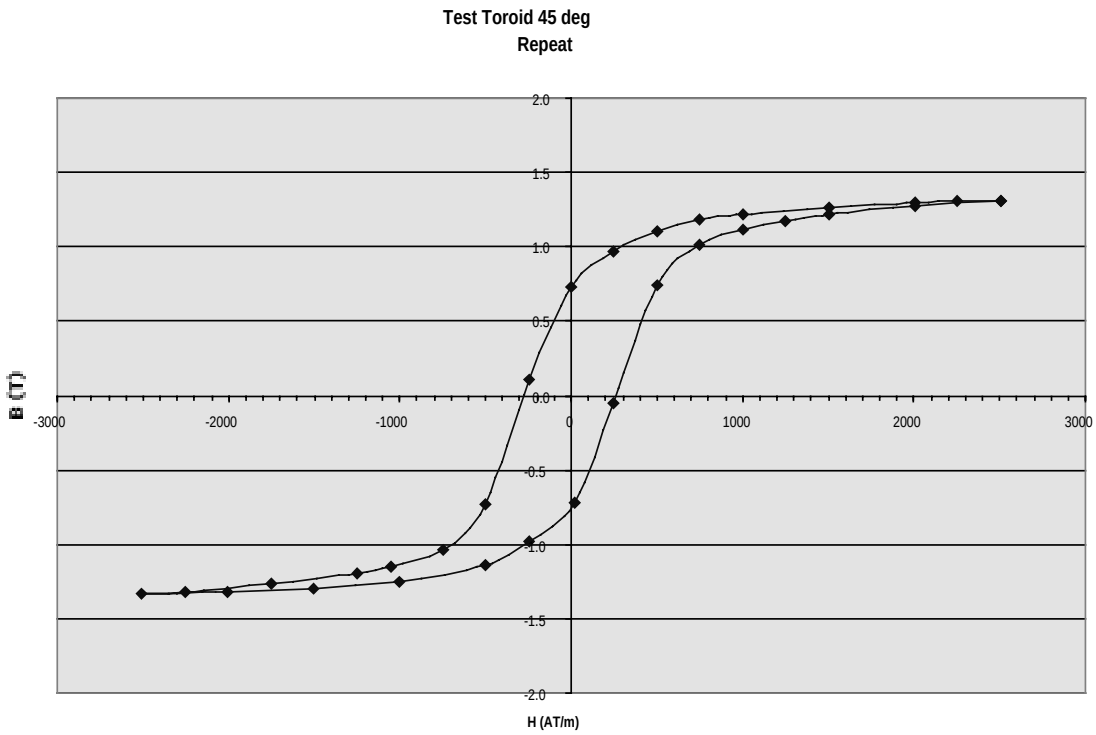

Test Toroid 90 deg
B (T)
H (AT/m)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-3000.0
-2000.0
-1000.0
0.0
1000.0
2000.0
3000.0

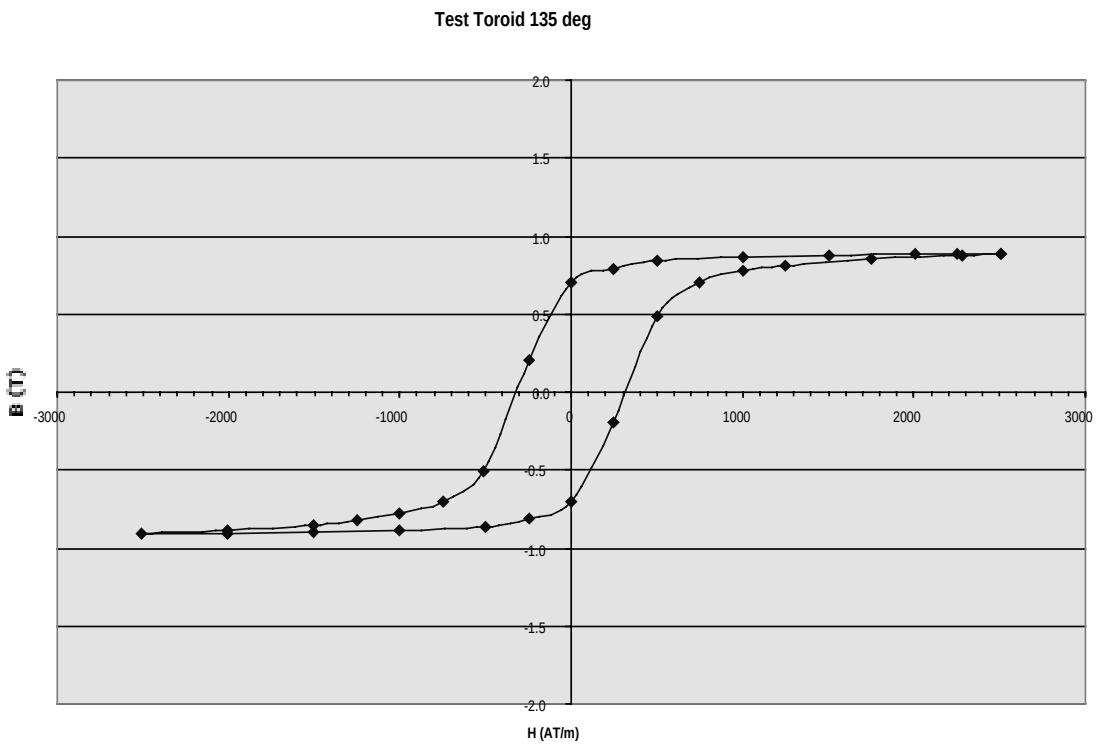

Test Toroid 45 deg
B (T)
H (AT/m)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-3000.0
-2000.0
-1000.0
0.0
1000.0
2000.0
3000.0


Test Toroid 10 deg
B (T)
H (AT/m)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-3000.0
-2000.0
-1000.0
0.0
1000.0
2000.0
3000.0

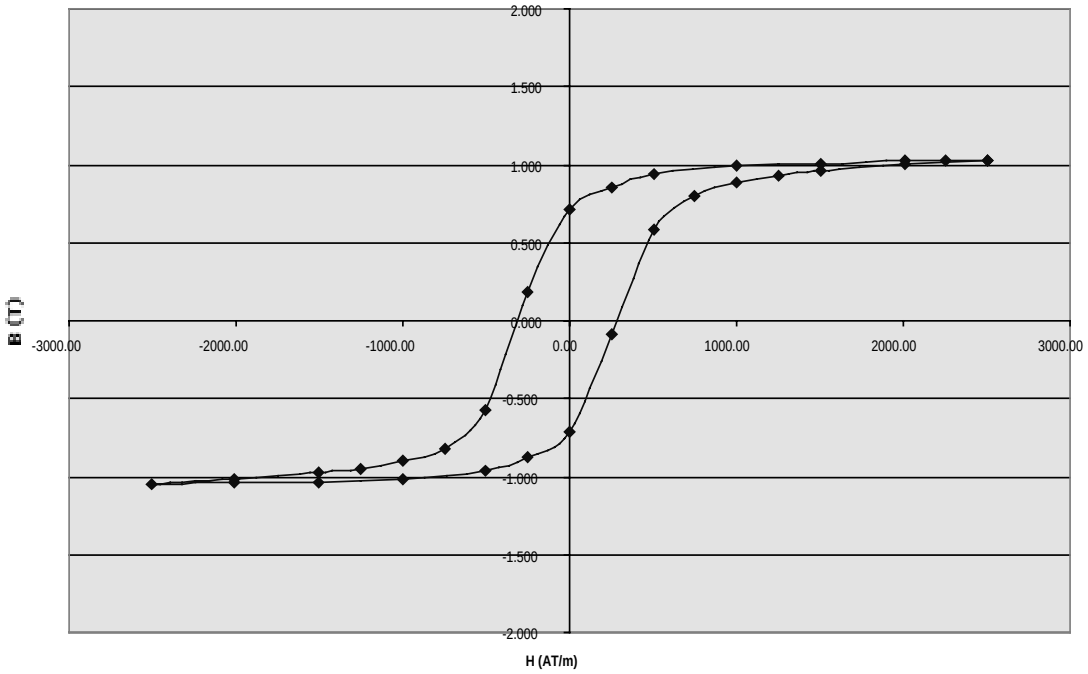
Integrator: R=10K, C=4.945 uF									
Coil turns		400							
Toroid mean radius		0.254	m						
Sensor	90 deg				Sensor	180 deg			
# of turns	50				# of turns	50			
Area=	9.68E-04	sq meters			Area=	9.68E-04	sq meters		
I	H	Tesla	Int adj	Integrator	I	H	Tesla	Int adj	Integrator
amps	Aturns/m	1.02		volts	amps	Aturns/m	1.02		volts
10.00	2506.38	1.025	1.005	0.000	10.00	2506.38	0.857	0.840	0.000
9.00	2255.74	1.022	1.002	-0.001	9.00	2255.74	0.855	0.839	0.000
8.00	2005.10	1.018	0.998	-0.004	8.00	2005.10	0.854	0.837	0.000
7.00	1754.46	1.013	0.993	-0.007	7.00	1754.46	0.853	0.836	0.000
6.00	1503.83	1.007	0.987	-0.011	6.00	1503.83	0.847	0.831	-0.004
5.00	1253.19	0.998	0.978	-0.018	4.00	1002.55	0.840	0.823	-0.010
4.00	1002.55	0.986	0.966	-0.028	2.00	501.28	0.818	0.802	-0.030
3.00	751.91	0.969	0.950	-0.043	0.00	0.00	0.694	0.680	-0.150
2.00	501.28	0.933	0.915	-0.076	-1.10	-275.70	0.111	0.109	-0.720
1.00	250.64	0.856	0.839	-0.150	-2.00	-501.28	-0.461	-0.452	-1.280
0.00	0.00	0.722	0.707	-0.280	-3.00	-751.91	-0.677	-0.664	-1.490
-1.00	-250.64	0.159	0.156	-0.830	-4.00	-1002.55	-0.750	-0.735	-1.560
-2.00	-501.28	-0.577	-0.566	-1.550	-5.00	-1253.19	-0.792	-0.777	-1.600
-3.00	-751.91	-0.824	-0.808	-1.790	-6.00	-1503.83	-0.814	-0.798	-1.620
-4.20	-1052.68	-0.918	-0.900	-1.880	-8.00	-2005.10	-0.846	-0.829	-1.650
-5.00	-1253.19	-0.940	-0.921	-1.900	-10.00	-2506.38	-0.878	-0.861	-1.680
-6.00	-1503.83	-0.982	-0.963	-1.940	-8.00	-2005.10	-0.869	-0.852	-1.670
-8.00	-2005.10	-1.035	-1.015	-1.990	-6.00	-1503.83	-0.870	-0.853	-1.670
-10.00	-2506.38	-1.057	-1.037	-2.010	-4.00	-1002.55	-0.862	-0.845	-1.660
-8.00	-2005.10	-1.049	-1.028	-2.000	-2.00	-501.28	-0.832	-0.816	-1.630
-6.00	-1503.83	-1.041	-1.020	-1.990	-1.00	-250.64	-0.793	-0.778	-1.590
-4.00	-1002.55	-1.022	-1.002	-1.970	0.00	0.00	-0.692	-0.679	-1.490
-2.00	-501.28	-0.952	-0.934	-1.900	1.00	250.64	-0.184	-0.180	-0.990
0.00	0.00	-0.720	-0.705	-1.670	2.00	501.28	0.488	0.478	-0.330
1.00	250.64	-0.171	-0.167	-1.130	3.09	774.47	0.686	0.673	-0.134
2.00	501.28	0.582	0.571	-0.390	4.00	1002.55	0.745	0.731	-0.075
3.00	751.91	0.805	0.789	-0.170	5.00	1253.19	0.780	0.764	-0.040
4.00	1002.55	0.885	0.868	-0.090	6.00	1503.83	0.804	0.788	-0.015
5.00	1253.19	0.928	0.910	-0.046	7.00	1754.46	0.822	0.806	0.004
7.00	1754.46	0.982	0.963	0.009	8.00	2005.10	0.837	0.820	0.020
8.00	2005.10	1.000	0.980	0.028	9.00	2255.74	0.845	0.829	0.030
9.00	2255.74	1.015	0.996	0.045	10.00	2506.38	0.858	0.841	0.044
10.00	2506.38	1.027	1.007	0.058					

Integrator: R=10K, C=4.945 uF						Date:		1/15/99		
Coil turns		400				Name:		R. Trendler/W. Jaskierny		
Toroid mean radius		0.254	m							
Sensor	45 deg					Sensor	10 deg			
# of turns	50					# of turns	50			
Area=	9.68E-04	sq meters				Area=	9.68E-04	sq meters		
I	H	Tesla	Int adj	Integrator		I	H	Tesla	Int adj	Integrator
amps	Aturns/m	1.02		volts		amps	Aturns/m	1.02		volts
10.00	2506.38	1.306	1.280	0.000		10.00	2506.38	1.658	1.625	0.000
9.00	2255.74	1.297	1.271	-0.007		9.00	2255.74	1.622	1.590	-0.020
8.00	2005.10	1.287	1.262	-0.015		7.96	1995.08	1.600	1.568	-0.040
7.00	1754.46	1.274	1.249	-0.026		6.00	1503.83	1.545	1.515	-0.092
6.00	1503.83	1.259	1.235	-0.039		5.00	1253.19	1.508	1.478	-0.127
5.00	1253.19	1.239	1.215	-0.057		4.00	1002.55	1.456	1.427	-0.176
4.00	1002.55	1.213	1.189	-0.081		3.00	751.91	1.389	1.362	-0.240
3.00	751.91	1.174	1.151	-0.118		2.00	501.28	1.265	1.240	-0.360
2.00	501.28	1.100	1.078	-0.189		1.00	250.64	1.039	1.018	-0.580
1.00	250.64	0.956	0.938	-0.328		0.00	0.00	0.721	0.707	-0.890
0.00	0.00	0.738	0.724	-0.540		-1.00	-250.64	-0.005	-0.005	-1.600
-1.00	-250.64	0.084	0.082	-1.180		-2.00	-501.28	-0.925	-0.907	-2.500
-2.00	-501.28	-0.723	-0.709	-1.970		-3.00	-751.91	-1.294	-1.268	-2.860
-3.00	-751.91	-1.031	-1.011	-2.270		-4.20	-1052.68	-1.438	-1.410	-3.000
-4.20	-1052.68	-1.135	-1.112	-2.370		-5.00	-1253.19	-1.521	-1.491	-3.080
-5.00	-1253.19	-1.197	-1.174	-2.430		-6.00	-1503.83	-1.574	-1.543	-3.130
-6.00	-1503.83	-1.240	-1.216	-2.470		-8.00	-2005.10	-1.647	-1.615	-3.200
-8.00	-2005.10	-1.293	-1.267	-2.520		-10.00	-2506.38	-1.700	-1.666	-3.250
-10.00	-2506.38	-1.335	-1.309	-2.560		-8.00	-2005.10	-1.650	-1.618	-3.200
-9.00	-2255.74	-1.326	-1.300	-2.550		-6.00	-1503.83	-1.595	-1.564	-3.144
-7.00	-1754.46	-1.308	-1.282	-2.530		-4.00	-1002.55	-1.511	-1.481	-3.060
-5.00	-1253.19	-1.268	-1.244	-2.490		-2.00	-501.28	-1.309	-1.283	-2.860
-3.00	-751.91	-1.209	-1.185	-2.430		0.00	0.00	-0.739	-0.725	-2.300
-1.00	-250.64	-0.986	-0.967	-2.210		1.04	260.66	0.075	0.074	-1.500
0.00	0.00	-0.743	-0.728	-1.970		2.00	501.28	0.920	0.902	-0.670
1.05	263.17	-0.020	-0.020	-1.260		3.00	751.91	1.255	1.230	-0.340
2.00	501.28	0.737	0.722	-0.516		4.00	1002.55	1.396	1.369	-0.200
3.00	751.91	1.011	0.991	-0.246		5.00	1253.19	1.476	1.447	-0.120
4.05	1015.08	1.119	1.097	-0.138		6.00	1503.83	1.530	1.500	-0.065
5.00	1253.19	1.174	1.151	-0.083		7.09	1777.02	1.576	1.545	-0.019
6.00	1503.83	1.214	1.190	-0.042		8.00	2005.10	1.607	1.576	0.014
7.00	1754.46	1.245	1.220	-0.010		9.00	2255.74	1.636	1.604	0.044
8.00	2005.10	1.269	1.244	0.015		10.00	2506.38	1.659	1.627	0.068
9.00	2255.74	1.290	1.265	0.038						
10.00	2506.38	1.307	1.282	0.056						

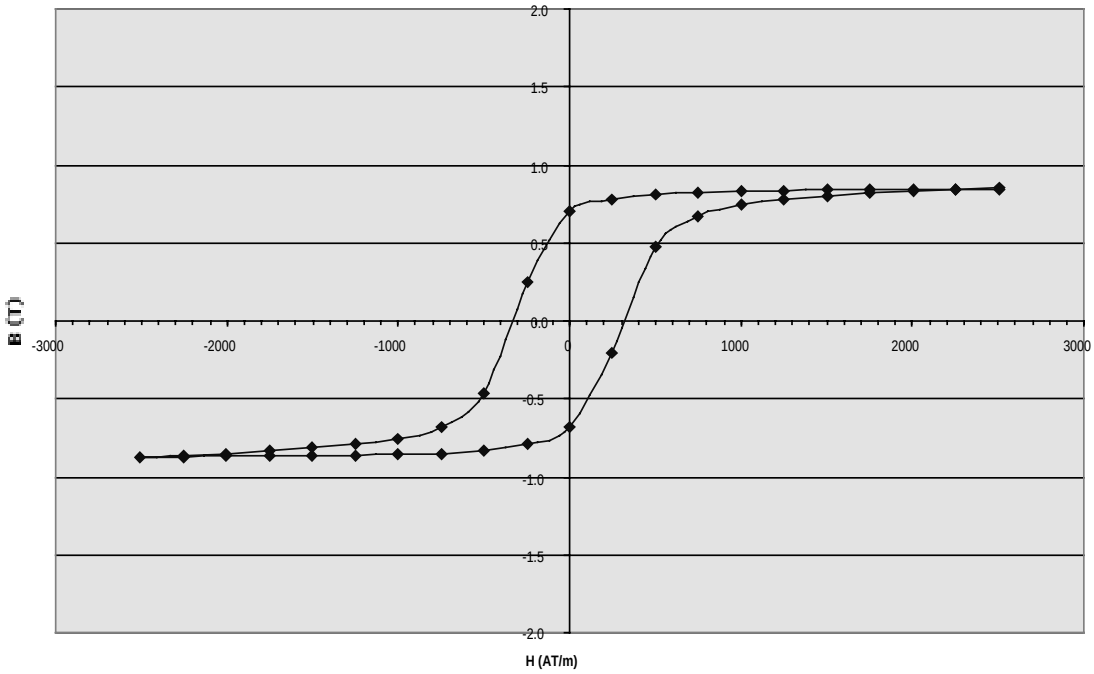

Test Toroid 45 deg
Repeat
B (T)
H (AT/m)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-3000
-2000
-1000
0
1000
2000
3000


Test Toroid 135 deg
B (T)
H (AT/m)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-3000
-2000
-1000
0
1000
2000
3000

Test Toroid 270 deg

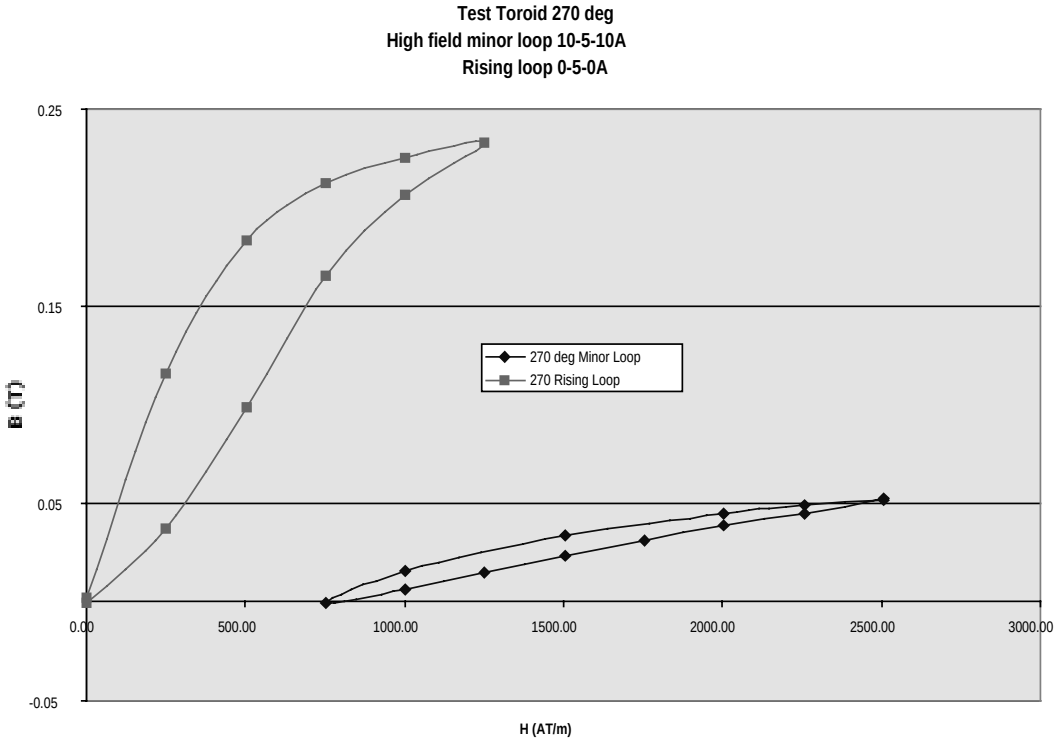


Test Toroid 180 deg Repeat



1/26/99 Data										
Sensor	45 deg					Sensor	135 deg			
# of turns	50					# of turns	50			
Area=	9.68E-04	sq meters				Area=	9.68E-04	sq meters		
I	H	Tesla	Int adj	Integrator		I	H	Tesla	Int adj	Integrator
amps	Aturns/m	1.02		volts		amps	Aturns/m	1.02		volts
10.00	2506.38	1.312	1.287	0.000		10.00	2506.38	0.887	0.870	0.000
9.00	2255.74	1.304	1.279	-0.007		9.00	2255.74	0.885	0.868	-0.001
8.00	2005.10	1.294	1.268	-0.015		8.00	2005.10	0.882	0.865	-0.003
6.00	1503.83	1.267	1.242	-0.040		6.00	1503.83	0.876	0.859	-0.007
4.00	1002.55	1.220	1.196	-0.084		4.00	1002.55	0.866	0.849	-0.016
3.00	751.91	1.182	1.158	-0.120		2.00	501.28	0.840	0.824	-0.040
2.00	501.28	1.109	1.087	-0.190		1.00	250.64	0.792	0.777	-0.086
1.00	250.64	0.964	0.945	-0.330		0.00	0.00	0.700	0.686	-0.175
0.00	0.00	0.728	0.714	-0.560		-1.00	-250.64	0.204	0.200	-0.660
-1.00	-250.64	0.104	0.102	-1.170		-2.06	-516.31	-0.511	-0.501	-1.360
-2.00	-501.28	-0.734	-0.720	-1.990		-3.00	-751.91	-0.706	-0.692	-1.550
-3.00	-751.91	-1.032	-1.011	-2.280		-4.00	-1002.55	-0.779	-0.764	-1.620
-4.20	-1052.68	-1.145	-1.123	-2.390		-5.00	-1253.19	-0.821	-0.805	-1.660
-5.00	-1253.19	-1.198	-1.175	-2.440		-6.00	-1503.83	-0.853	-0.836	-1.690
-7.00	-1754.46	-1.261	-1.236	-2.500		-8.00	-2005.10	-0.885	-0.867	-1.720
-9.00	-2255.74	-1.324	-1.298	-2.560		-10.00	-2506.38	-0.906	-0.889	-1.740
-10.00	-2506.38	-1.336	-1.310	-2.570		-8.00	-2005.10	-0.908	-0.890	-1.740
-8.00	-2005.10	-1.317	-1.291	-2.550		-6.00	-1503.83	-0.899	-0.881	-1.730
-6.00	-1503.83	-1.298	-1.273	-2.530		-4.00	-1002.55	-0.890	-0.872	-1.720
-4.00	-1002.55	-1.249	-1.224	-2.480		-2.00	-501.28	-0.860	-0.843	-1.690
-2.00	-501.28	-1.138	-1.116	-2.370		-1.00	-250.64	-0.811	-0.795	-1.640
-1.00	-250.64	-0.977	-0.958	-2.210		0.00	0.00	-0.700	-0.686	-1.530
0.07	17.54	-0.723	-0.709	-1.960		1.00	250.64	-0.191	-0.187	-1.030
1.00	250.64	-0.052	-0.051	-1.300		2.00	501.28	0.491	0.482	-0.360
2.00	501.28	0.742	0.727	-0.520		3.00	751.91	0.704	0.690	-0.150
3.00	751.91	1.016	0.996	-0.250		4.00	1002.55	0.774	0.759	-0.080
4.00	1002.55	1.116	1.094	-0.150		5.00	1253.19	0.806	0.790	-0.048
5.00	1253.19	1.176	1.153	-0.090		7.00	1754.46	0.850	0.834	-0.003
6.00	1503.83	1.215	1.191	-0.050		9.12	2285.82	0.880	0.862	0.027
8.00	2005.10	1.274	1.249	0.010		10.00	2506.38	0.889	0.871	0.037
10.00	2506.38	1.312	1.287	0.049						

1/26/99 Data										
Sensor	270 deg					Sensor	180 deg			
# of turns	50					# of turns	50			
Area=	9.68E-04	sq meters				Area=	9.68E-04	sq meters		
I	H	Tesla	Int adj	Integrator		I	H	Tesla	Int adj	Integrator
amps	Aturns/m	1.02		volts		amps	Aturns/m	1.02		volts
10.00	2506.38	1.030	1.010	0.000		10.00	2506.38	0.844	0.828	0.000
9.00	2255.74	1.027	1.007	-0.002		9.00	2255.74	0.844	0.827	0.000
8.00	2005.10	1.022	1.002	-0.006		8.00	2005.10	0.843	0.827	-0.001
6.00	1503.83	1.010	0.990	-0.016		7.00	1754.46	0.842	0.826	-0.002
4.00	1002.55	0.990	0.971	-0.034		6.00	1503.83	0.840	0.824	-0.004
2.00	501.28	0.936	0.917	-0.086		5.00	1253.19	0.838	0.821	-0.006
1.00	250.64	0.859	0.842	-0.160		4.00	1002.55	0.833	0.817	-0.011
0.00	0.00	0.715	0.701	-0.300		3.00	751.91	0.826	0.810	-0.017
-1.00	-250.64	0.183	0.179	-0.820		2.00	501.28	0.812	0.796	-0.032
-2.00	-501.28	-0.573	-0.562	-1.560		1.00	250.64	0.775	0.760	-0.068
-3.00	-751.91	-0.819	-0.803	-1.800		0.00	0.00	0.699	0.686	-0.142
-4.00	-1002.55	-0.902	-0.885	-1.880		-1.00	-250.64	0.252	0.247	-0.580
-5.00	-1253.19	-0.947	-0.928	-1.922		-2.00	-501.28	-0.461	-0.452	-1.278
-6.00	-1503.83	-0.976	-0.957	-1.950		-3.00	-751.91	-0.679	-0.665	-1.490
-8.00	-2005.10	-1.019	-0.999	-1.990		-4.00	-1002.55	-0.760	-0.745	-1.569
-10.00	-2506.38	-1.051	-1.030	-2.020		-5.00	-1253.19	-0.789	-0.773	-1.596
-8.00	-2005.10	-1.042	-1.021	-2.010		-6.00	-1503.83	-0.814	-0.798	-1.620
-6.00	-1503.83	-1.033	-1.013	-2.000		-7.00	-1754.46	-0.834	-0.818	-1.639
-4.00	-1002.55	-1.014	-0.994	-1.980		-8.00	-2005.10	-0.850	-0.833	-1.653
-2.00	-501.28	-0.964	-0.945	-1.930		-9.00	-2255.74	-0.862	-0.845	-1.664
-1.00	-250.64	-0.874	-0.857	-1.840		-10.00	-2506.38	-0.873	-0.856	-1.674
0.00	0.00	-0.712	-0.698	-1.680		-9.00	-2255.74	-0.872	-0.855	-1.672
1.00	250.64	-0.091	-0.089	-1.070		-8.00	-2005.10	-0.870	-0.853	-1.669
2.00	501.28	0.581	0.569	-0.410		-7.00	-1754.46	-0.868	-0.851	-1.666
3.00	751.91	0.804	0.788	-0.190		-6.00	-1503.83	-0.866	-0.849	-1.663
4.00	1002.55	0.888	0.871	-0.106		-5.00	-1253.19	-0.863	-0.846	-1.659
5.00	1253.19	0.931	0.912	-0.063		-4.00	-1002.55	-0.857	-0.841	-1.653
6.00	1503.83	0.961	0.942	-0.032		-3.00	-751.91	-0.849	-0.833	-1.644
8.00	2005.10	1.002	0.983	0.010		-2.00	-501.28	-0.834	-0.817	-1.628
10.00	2506.38	1.032	1.011	0.040		-1.00	-250.64	-0.786	-0.770	-1.580
						0.00	0.00	-0.685	-0.671	-1.480
						1.00	250.64	-0.206	-0.202	-1.010
						2.00	501.28	0.478	0.469	-0.338
						3.00	751.91	0.674	0.661	-0.145
						4.00	1002.55	0.741	0.727	-0.078
						5.00	1253.19	0.776	0.761	-0.043
						6.00	1503.83	0.800	0.784	-0.019
						7.00	1754.46	0.818	0.802	-0.0002
						8.00	2005.10	0.832	0.816	0.015
						9.00	2255.74	0.845	0.828	0.028
						10.00	2506.38	0.855	0.838	0.0388

Two additional measurements were made and plotted to further evaluate the magnetic properties of the steel. With the first plot (the “minor loop”), the current was set to 10A then lowered in steps to 5A and then raised in steps back to 10A. Observe that this plot is relative in that it does not show the actual baseline B values. The second plot was obtained by raising the current in steps from zero to 5A and then back to zero. The data spreadsheet and plots follow:

Integrator: R=10K, C=4.945 uF								Date:	1/15/99	
Coil turns	400							Name:	R. Trendler/W. Jaskierny	
Toroid mean radi	0.254	m							1/26/99 Data	
Sensor	270 deg					Sensor	270 deg			
# of turns	50					# of turns	50			
Area=	9.68E-04	sq meters				Area=	9.68E-04	sq meters		
I	H	Tesla	Int adj	Integrator		I	H	Tesla	Int adj	Integrator
amps	Aturns/m	1.02		volts		amps	Aturns/m	1.02		volts
10.00	2506.38	0.052	0.051	0.000		0.00	0.00	0.000	0.000	0.000
9.00	2255.74	0.049	0.048	-0.002		1.00	250.64	0.037	0.036	0.038
8.00	2005.10	0.045	0.044	-0.006		2.00	501.28	0.099	0.097	0.101
6.00	1503.83	0.034	0.033	-0.015		3.00	751.91	0.166	0.162	0.168
4.00	1002.55	0.015	0.015	-0.033		4.00	1002.55	0.206	0.202	0.210
3.00	751.91	0.000	0.000	-0.048		5.00	1253.19	0.233	0.228	0.238
4.00	1002.55	0.007	0.007	-0.040		4.00	1002.55	0.225	0.221	0.232
5.00	1253.19	0.015	0.015	-0.031		3.00	751.91	0.213	0.209	0.222
6.00	1503.83	0.024	0.023	-0.022		2.00	501.28	0.183	0.180	0.195
7.00	1754.46	0.031	0.030	-0.014		1.00	250.64	0.116	0.114	0.131
8.00	2005.10	0.038	0.038	-0.006		0.00	0.00	0.002	0.002	0.021
9.00	2255.74	0.045	0.044	0.001						
10.00	2506.38	0.052	0.051	0.009