SOME HYSTERESIS TESTS ON IRON.

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From curves which have been drawn to show the effect of cyclic magnetizing processes in iron and in other metals, there appears one feature which is common to all; a tendency on the part of the metal to retain any magnetic condition which it may have acquired.

This tendency becomes quite apparent whenever a change is made in the character of the magnetizing process. When, for instance the magnetizing force has been increased through an appreciable change of value and then is decreased through the same range in value, we find that the magnetism which was acquired by the metal is not decreased at the same rate at which it was acquired.

This reluctance, on the part of the metal, to change its magnetic condition is the same when, after the magnetizing force has been wholly or partly withdrawn, it is again increased.

The state of magnetization, whether the iron is fully or only partly magnetized, makes no difference in the reluctance to change the condition when the magnetizing force is changed. For instance, in the case where the current has been reversed and the magnetism wholly withdrawn, the iron is then in an apparently neutral condition, but it will be found when upon applying the current in the former direction that the iron is not susceptible of the same magnetic changes that it would be were it in the neutral state, but it acts the same as when it still retained some of its magnetism.

The reluctance, or the resistance to magnetization, of the metal is much more apparent at the beginning of the change in the magnetizing force. If a piece of iron is magnetized and demagnetized, then magnetized in the opposite direction and again demagnetized, then again magnetized in the former direction, or strictly speaking, if the magnetizing force has been carried through a complete cycle; that is, the current has attained its highest positive value and been reduced, then reversed and attained its highest negative value, and again reduced, again reversed and carried to its highest value; the curves plotted, showing the relation of the induction in the iron to the magnetizing force will form a loop. This loop shows the tendency of the magnetism to lag behind the magnetizing force when changes are made in the condition of the force. The loop thus formed shows by its area the loss of work per cubic centimeter of iron in carrying the magnetism through one complete cycle.

The name Magnetic Hysteresis has been given to the tendency of the magnetism to lag behind the magnetizing force; the loop formed is the hysteresis loop, and the work lost the hysteresis loss.

IMPORTANCE OF HYSTERESIS CURVES:-

From the hysteresis curves obtained from various kinds of iron, is shown the relative magnetic retentivities of the irons.

In armature cores, transformer cores, and magnets, the retentivity of the iron is one of the most important features to be comsidered.

The retentivity of iron is its ability to hold magnetism, and the permeability the ability to acquire magnetism.

In the armature core of a dynamo and in transformer cores where the iron is subject to rapid alternations in the direction of magnetism, it is required to have iron of high permeability and of low retentivity. Hence the iron which shows a curve in which the induction rises rapidly with a small increase in the magnetizing force and quickly reaches its highest value, giving a narrow loop of small area, is the iron to be used. Such an iron is mild steel or Sweedish iron.

For the field magnet of a dynamo or motor or for any electro-magnet, iron having a very high permeability is required. Hence, a curve which shows a very rapid increase of induction for a small current, is the curve of the iron most desirable.

For permanent magnets the permeability of the iron is the unimportant factor, while the retentivity is of great importance.

For such an iron the curve will show a slower increase in induction and the loop will be wide and of large area.

The extra work required due to hysteresis losses, varies from 1 % to 5 % in armature and transformer cores.

To plot a hysteresis curve it is first necessary to know the magnetizing force, H, and the induction, B. Now in a coil consisting of a single turn of wire, enclosing an area A, and carrying a current I, the magnetic moment = A I. If the turns in the coil be increased to N and an iron core of cross-section A and of permeability μ, be inserted in the coil, the magnetic moment is correspondingly increased. The magnetic moment ml, where m is the pole strength and l the length of the coil, is now equal to

$$\mu A N I \quad \text{or} \quad m = \frac{\mu A N I}{l}$$

Since there are $4 \pi m$ lines of force coming from a pole of strength m the total magnetic flux = $4 \pi m$ =

$$4 \pi \frac{\mu A S I}{l} = \frac{4 \pi S I}{\frac{l}{A \mu}}$$

Through the similarity of the magnetic and electrical circuits we have the Magnetic Flux corresponding to the current strength, the magnetizing force corresponding to the E. M. F., and the reluctance corresponding to the resistance, hence:

$$M.F. = \frac{M.\ M.\ F.}{R} = \frac{4 \pi S I}{\frac{1}{A \mu}}$$

Therefore the M. M. F. is proportional to $4\pi S I$ and the reluctance is proportional to $\frac{l}{A\mu}$. The inductance, B per sq. cm. is found by dividing the total flux by the area of the magnetic coil or

$$B = \frac{M.F.}{A} = \cfrac{4\pi S I}{\cfrac{A l}{A\mu}} = \cfrac{4\pi S I}{\cfrac{l}{\mu}}$$

The magnetizing force H is equal to the induction ÷ by the permeability, or

$$H = \frac{B}{\mu} = \cfrac{4\pi S I}{\cfrac{\mu l}{\mu}} = \frac{4\pi S I}{l}$$

If the current is in amperes and other factors in C. G. S. units, $H = \frac{4\pi S I}{10\, l}$. The magnetizing force is equal to,

$\frac{4\pi}{10}$ x the ampere turns per unit length.

The wrought iron ring used in the experiments consisted of wrought iron sheets, or stove pipe iron, riveted firmly together and turned to the following dimensions, the cross section being rectangular.

DIMENSIONS.

External diameter = 18.65 cm.
Internal " = 12.7 "
Mean " = 15.675 "
Mean Circumference = 49.25 "
Cross sectional area = 2.97 cm. x 1.7 cm.

The ring was wound uniformly with a primary coil of 1500 turns, and a secondary of 800 turns. The cast iron ring was turned from a specially made casting to the following dimensions:

External diameter = 18.7 cm.
Internal " = 12.7 "
Thickness = 2.445 "
Width = 3.025 "

The winding of the coils ~~was~~ were similar to that of the ~~cast~~ wrought iron ring. Both rings were mounted on wooden bases, and the terminals connected to binding posts for convenience in making the test.

The method used in making the test may be found by referring to Ewing's Magnetic Induction in Iron and Other Metals, Chap. 111.

The constant of the galvonometer was determined by use of the formula,

$$Q. = \frac{4\pi A S N I}{10 R l} = Q_o\delta$$

where A = area of calibrating coil, S = turns in primary coil, N = turns in secondary coil, I = current, R = resistance of galvonometer circuit, l = length of primary coil, δ = galvonometer throw, and Q_o galvonometer constant.

The calibrating coil consisted of 255 turns in the primary and 280 in the secondary. The length of the primary is 13.1 cm. and the diameter of the wooden core is 3.92 cm. The current used in calibrating was 13.1 amperes and the galvonometer deflection 8.3 scale divisions. The resistance of the galvonometer circuit was 1000 ohms in the galvonometer, and 15 in the secondary coil and circuit, a total of 1015 ohms. The constant obtained was 128.55.

The valves of B used in the curves were found by multiplying the galvonometer constant by the $\leq \delta$ for the current corresponding in the tables of data.

The valves of H are found by multiplying the constant valve $\frac{4 \pi S}{10 l}$, where S = total number of turns in primary coil of ring and l = mean circumference of ring; by the current strength in each case.

The following data were taken and plotted as shown by the curves.

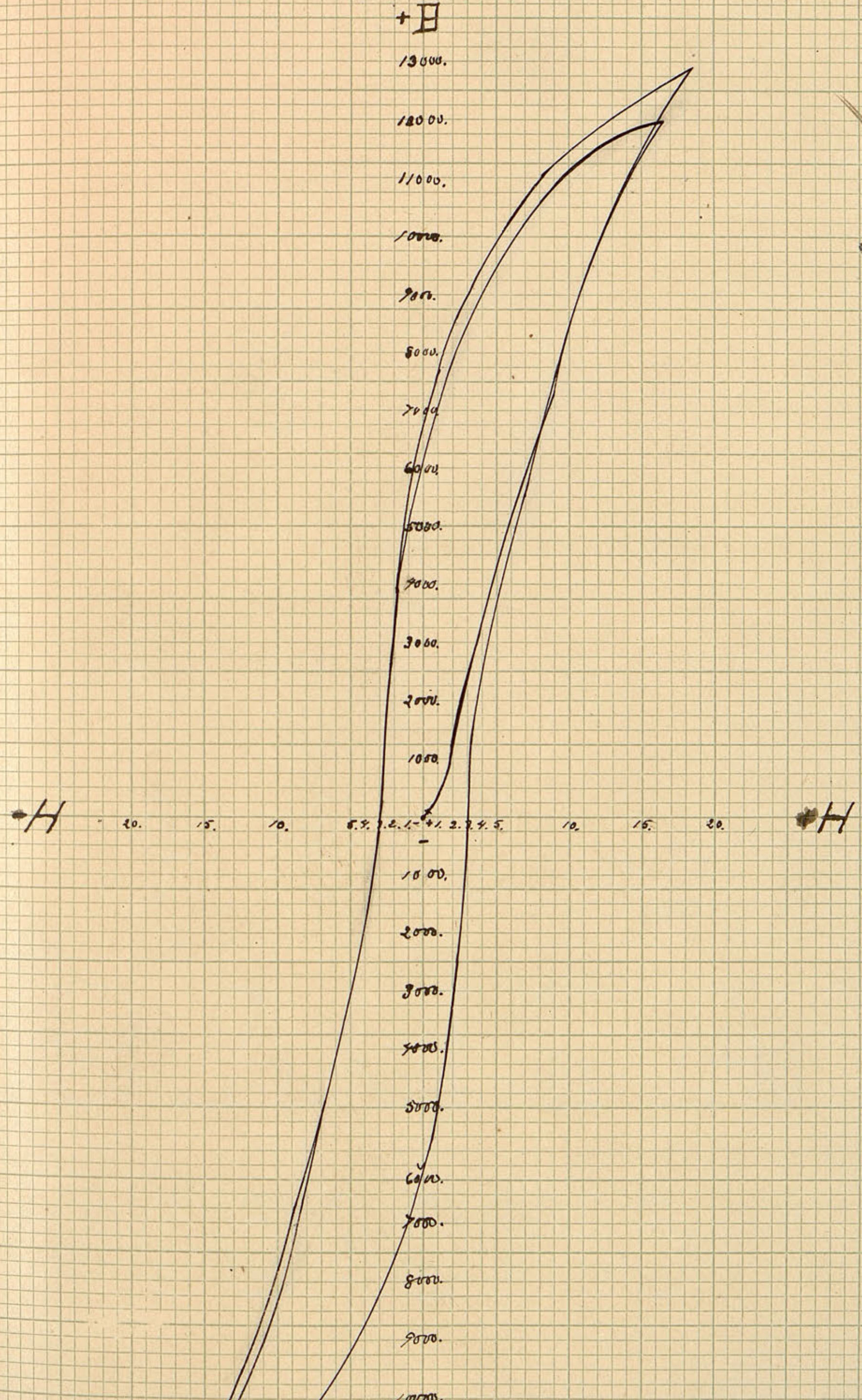
Data for Wrought Iron Ring.

Magnetizing Current = I.	Scale Gerv.	Scale Deflection	Throw δ	$\Sigma\ \delta$	Magnetizing Force = H.	Induction = B.
.016	40.	38.9	1.1	1.1	.6123	141.41
.028	40	38.1	1.9	3.0	1.0715	385.65
.046	40	34.0	6.0	9.0	1.7604	1156.95
.065	40	33.6	6.4	15.4	2.4875	1979.67
.100	40	30.8	9.2	24.6	3.8270	3162.33
.161	40	25.9	14.1	38.7	6.1614	4962.03
.231	40	22.1	17.9	56.6	8.8403	7275.93
.282	40	26.3	13.7	70.3	10.7921	9037.06
.350	40	26.8	13.2	83.5	13.3945	10733.92
.424	40	29.7	10.3	93.8	16.2664	12057.99
.480	40	33.8	6.2	100.0	18.3696	12855,00
.418	40	42.6	-2.6	97.4	15.9968	12520.77
.338	15	18.0	-3.0	94.4	12.9352	12135.12
.269	15	18.9	-3.9	90.5	10.2946	11633.78
.213	15	19.2	-4.2	86.3	8.1515	11093.87
.150	15	22.3	-7.3	79.0	5.7405	10155.45
.090	15	23.1	-8.1	70.9	3.4443	9114.30
.060	15	20.8	-5.8	65.1	2.2962	8368.61
.040	15	18.9	-3.9	61.2	1.5308	7867.26
.026	15	19.3	-4.3	56.9	.9950	7314.49
.017	15	17.9	-2.9	54.0	.6506	6941.70
-.017	15	23.0	-8.0	46.0	-.6506	5913.30
-.025	15	19.2	-4.2	41.8	-.9567	5373.39
-.042	15	24.1	-9.1	32.7	-1.6073	4203.58
-.060	15	29.2	-14.2	18.5	-2.2962	2378.18
-.090	15	46.2	-31.2	-12.7	-3.4443	-1632.59
-.208	15	47.2	-32.2	-44.9	-7.9602	-5771.90
-.260	15	30.0	-15.0	-59.9	-9.9502	-7700.15
-.327	15	29.6	-14.6	-74.5	-12.5143	-9576.97
-.402	15	26.5	-11.5	-86.0	-15.3845	-11055.30
-.454	15	20.8	-5.8	-91.8	-17.3745	-11800.89
-.395	15	13.4	1.6	-90.2	-15.1166	-11595.21
-.313	40	36.9	3.1	-87.1	-11.9785	-11299.55
-.250	40	36.2	3.8	-83.3	-9.5670	-10708.21
-.199	40	35.7	4.3	-79.0	-7.6157	-10155.44
-.135	40	32.8	7.2	-71.8	-5.1664	-9229.89
-.085	40	32.7	7.3	-64.5	-3.2529	-8391.48
-.055	40	34.6	5.4	-59.1	-2.1049	-7597.30
-.040	40	36.4	3.6	-55.5	-1.5308	-7134.53
-.023	40	35.9	4.1	-51.4	-.8802	-6607.47

Data for Wrought Iron Ring.

Magnetizing current = I.	Scale zero	Scale Deflection	Throw δ	Σδ	Magnetizing Force = H	Induction = B
-.015	40	37.3	2.7	-48.7	-.5741	-6260.38
.015	45	38.4	6.6	-42.1	.5741	-5411.95
.024	45	41.0	4.0	-38.1	.9185	-4897.75
.040	45	37.0	8.0	-30.1	1.5308	-3869.36
.056	45	32.8	12.2	-17.9	2.1431	-2307.05
.083	45	16.0	29.0	+11.1	3.1764	1426.09
.192	45	11.1	33.9	45.0	7.3478	5784.75
.242	45	29.6	15.4	60.4	9.2613	7764.42
.306	45	30.8	14.2	74.6	11.7106	9589.83
.378	45	33.7	11.3	85.9	14.4660	11042.45
.430	45	38.5	6.5	92.4	16.5461	11878.02
.375	5	6.6	-1.6	90.8	14.3512	11672.34
.300	5	7.9	-2.9	87.9	11.4810	11295.55
.246	5	8.8	-3.8	84.1	9.4144	10811.06
.190	5	9.1	-4.1	80.0	7.2713	10284.00
.130	5	12.0	-7.0	73.0	4.9751	9384.15
.080	5	12.2	-7.2	65.8	3.0616	8458.59
.055	5	10.0	-5.0	60.8	2.1049	7815.84
.040	5	8.4	-3.4	57.4	1.5308	7378.77
.023	5	8.8	-3.8	53.6	.8802	6890.28
.015	5	7.6	-2.6	51.0	.5741	6556.05
-.015	5	12.1	-7.1	43.9	-.5741	5643.35
-.023	5	8.8	-3.8	40.1	-.8802	5154.85
-.039	5	12.4	-7.4	32.7	-1.4925	4203.59
-.053	5	16.1	-11.1	21.6	-2.0373	2776.68
-.080	5	31.3	-26.3	-4.7	-3.0616	-604.18
-.186	5	41.0	-36.0	-40.7	-7.1182	-5231.98
-.232	5	19.5	-14.5	-55.2	-8.8786	-7095.96
-.280	5	19.9	-14.9	-70.1	-11.0983	-9011.36
-.358	5	16.5	-11.5	-81.6	-13.7006	-10489.68
-.416	5	12.4	-7.4	-89.0	-15.9203	-11440.95

Hysteresis Curve for Wrought Iron.



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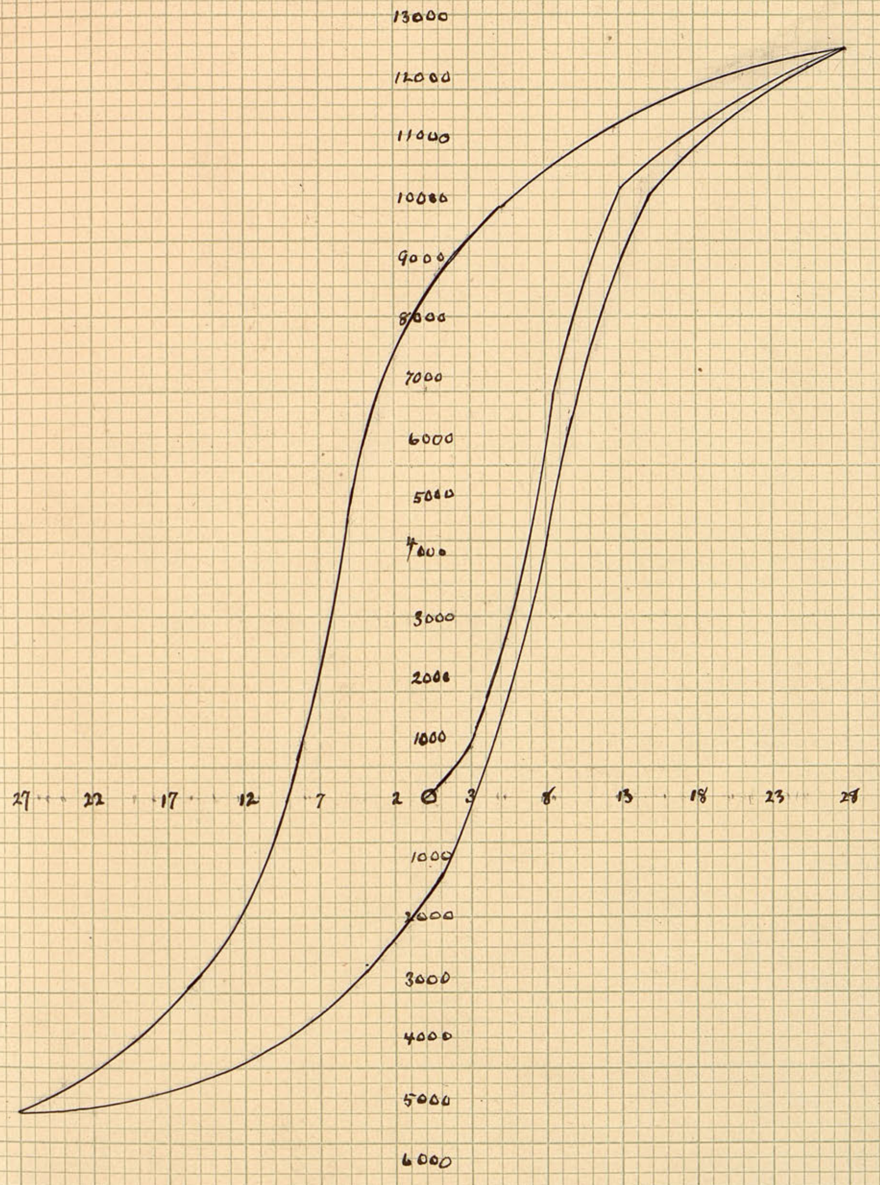
Data for Cast Iron Ring.

HYSTERESIS CURVE FOR CAST IRON.



Data for Cast Iron Ring.

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Current I	Zero	Deflection	Throw δ	Σ throws Σδ	Magnetising Force = H	Induction = B
.018	1.7	2.6	.9	.9	.6877	115.69
.03	1.7	2.8	1.1	2.0	1.1463	257.10
.054	1.7	4.3	2.6	4.6	2.0633	591.33
.084	1.7	6.2	4.5	9.1	3.2096	1169.80
.14	1.7	15.0	13.3	22.4	5.3494	2879.52
.23	1.7	32.1	30.4	52.8	8.7883	6787.44
.342	1.7	23.	21.3	74.1	13.0869	9364.55
.444	1.7	10.8	9.1	83.2	16.9576	10695.36
.551	1.7	9.3	7.6	90.8	21.0537	11672.34
.665	1.7	5.0	3.3	94.1	25.4096	12096.55
.736	1.7	4.7	3.0	97.1	28.1226	12466.10
.642	44.8	43.1	1.7	95.4	24.5308	12263.77
.53	45.	42.4	2.6	92.8	20.2513	11929.44
.416	44.8	41.8	3.0	89.8	15.8954	11543.79
.33	44.8	42.0	2.8	87.0	12.6093	11167.75
.22	44.8	40.1	4.7	82.3	8.4062	10579.66
.135	44.8	40.1	4.7	77.6	5.1583	9798.38
.081	44.8	41.5	3.3	74.3	3.0950	9390.26
.055	44.8	42.7	2.1	72.2	2.1015	9120.31
.031	44.8	42.6	2.2	70.0	1.1845	8837.50
.018	44.8	43.4	1.4	68.6	.6877	8818.53
.018	44.8	41.4	3.4	65.2	.6877	8381.46
.03	44.8	41.8	3.0	62.0	1.1463	7995.81
.054	44.8	40.3	4.5	57.7	2.0633	7399.62
.08	44.8	36.7	8.1	49.6	3.0568	6376.08
.132	44.8	21.4	13.4	36.2	5.0437	4653.51
.219	44.8	11.3	33.5	2.7	8.3680	909.46
.325	44.7	25.9	18.8	−16.1	12.4182	−2069.66
.408	44.7	36.3	8.4	−24.5	15.5897	−3149.47
.506	44.7	37.6	7.1	−31.6	19.3342	−4062.18
.63	44.7	39.2	5.5	−37.1	24.0723	−4753.10

I	Zero	Defl.	Δδ	Σδ	H	B.
.672	44.7	42.0	2.7	-39.8	25.6771	-5116.29
.59	44.7	43.3	1.4	-41.2	22.5439	-5296.26
.485	2.0	4.4	2.4	-38.8	18.5318	-4987.74
.385	2.0	4.8	2.8	-36.0	14.7109	-4627.80
.303	2.0	4.8	2.8	-33.2	11.5776	-4267.86
.205	2.0	6.4	4.4	-28.8	7.8331	-3702.24
.125	2.2	6.7	4.5	-24.3	4.7763	-3123.76
.078	2.2	5.4	3.2	-21.1	2.9804	-2712.41
.052	2.2	4.3	2.1	-19.0	1.9869	-2442.45
.03	2.2	4.2	2.0	-17.0	1.1463	-2169.25
.016	2.1	3.5	1.4	-15.6	.6113	-2005.38
.016	2.1	5.6	3.5	-12.1	.6113	-1555.45
.03	2.1	4.1	2.0	-10.1	1.1463	-1298.35
.052	2.1	6.5	4.4	-5.7	1.9869	-731.13
.079	2.1	9.4	7.3	1.6	3.0186	205.68
.127	2.0	25.1	23.1	24.7	4.8527	3173.57
.205	2.0	36.0	34.	58.7	7.8331	7544.27
.302	2.0	23.0	21.	79.7	11.5394	10082.82
.378	2.0	11.1	9.1	88.8	14.4434	11495.24
.47	2.0	9.6	7.6	96.4	17.9587	12392.22
.565	2.0	7.8	5.8	102.2	21.5886	13137.81
.627	2.0	5.2	3.2	105.4	23.9577	13549.17
.553	44.8	43.3	1.5	103.9	21.1301	13356.34
.45	45.0	42.5	2.5	101.4	17.1945	13034.97
.358	45.0	42.3	2.7	98.7	13.6792	12686.27
.284	45.0	42.4	2.6	96.1	10.8506	12353.65
.192	45.0	40.8	4.2	91.9	7.3363	11813.74
.118	45.0	40.7	4.3	87.6	4.5088	11244.88
.073	46.0	42.1	2.9	84.7	2.7893	10886.58
.05	45.0	43.1	1.9	828	1.9105	10643.94
.03	45.0	43.0	2.0	88.8	1.1463	10386.84

I	Zero	Deflec.	δ	Σ δ	H	B.
.017	45.0	43.7	1.3	79.5	.6496	10058.72
.017	45.0	41.7	3.3	76.2	.6496	9634.51
.03	45.0	43.1	1.9	74.3	1.1463	9390.26
.05	45.0	41.0	4.0	70.3	1.9105	8876.07
.073	45.0	38.7	6.3	64.0	2.7893	8227.20
.118	45.0	23.9	21.1	42.9	4.5088	5514.79
.191	45.0	10.4	34.6	8.3	7.2981	1066.96
.282	45.0	23.7	21.3	-13.	10.7752	-1671.15
.352	45.0	35.8	9.2	-21.2	13.4499	-2725.26
.44	45.0	37.4	7.6	-28.8	16.8124	-3702.24
.531	45.0	39.3	5.7	-33.5	20.2895	-43.06.42
.586	45.0	41.8	3.2	-36.7	22.3911	-4716.18

The area of the curves as plotted represent the work, W, lost per. sq. cm. during a single cycle; due to the hysteresis effect.

To obtain an equation for the work lost let N = the induction then $dW = I\ dN$, But $dW = \frac{4\pi n I}{10} = Hl$. n = number of turns in coil.

$I = \frac{Hl}{4\pi n}$, $dN = A n \cdot dB$, where A = cross section of coil.

$\therefore dW = I.\ dN = \frac{Hl}{4\pi n} . A n dB.$

$W = \frac{\text{Vol. of coil}}{4\pi} \int H . dB$ = total work lost during one complete cycle.

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