AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, April 25th, 1900.

The 142d meeting was held at 12 West 31st Street, this date, and was called to order at 8:35 P. M. by Manager Steinmetz.

THE CHAIRMAN:—The meeting is called to order. I give the floor to the Secretary to make some announcements.

SECRETARY POPE:—At the meeting of the Executive Committee this afternoon the following associate members were elected:

BARR, JOHN B.	Electrical Engineer General Electric Co., residence 234 Union Street, Schenectady, N. Y.	C P. Steinmetz. Ernest Berg. A. H. Armstrong.
BROWNE, WM. HAND, JR.	Asst. Professor of Electrical Engineering, The University of Illinois, Urbana, Ill.	R. B. Owens. Wm. Esty. Wm. S. Aldrich.
COLE, WM. HOWARD	Engineer, Ferrocarriles del Districto Federal, Mexico City, Mexico.	C. F. Beames. A. E. Worswick. P. H. Evans.
GUERRERO, JULIO	Associated with the Durango Electric Light Co., Victoria, 12 Durango, Mex.	C. F. Beames. P. H. Evans. M. T. Thompson.
GUTIERREZ, MANUEL R.	Professor of Physics, Normal School, Jalapa, Mexico.	M. T. Thompson. P. H. Evans. C. F. Beames.
HANSCOM, WM. W.	Chief Electrical Engineer, Union Iron Works, 612 O'Farrell Street, San Francisco, Cala.	F. F. Barbour. H. A. Russell. J. A. Lighthipe.
LEAMY, J. M.	Electrician, Dominion Government, 250 Lyon St., Ottawa, Canada.	T. Ahearn. A. A. Dion. Ralph W. Pope.
LIVSEY, J. H.	Salesman and Manager Detroit Office General Electric Company, 704 Chamber of Commerce, Detroit, Mich.	W. L. R. Emmet. Alex Dow. A. F. Walker.
MARSHALL, CLOYD	Designer of Electrical Machinery, Jenney Elec. M'f'g, Co., Indianapolis, Ind.	Harold B. Smith. W.E.Goldsbor'gh. C. P. Matthews.

McClure, William J.	Associated with H. D. Brown, Electrical Engineers and Contractors, residence, 259 West 52nd Street, New York City.	W. H. Ripley. F. B. Crocker. M. I. Pupin.
Moore, John Peabody	Tester, General Electric Co., P. O. Box 389, Schenectady, N. Y.	A. F. McKissick. R. W. Pope. W. E. Boileau.
Oolgaardt, J. J.	Electrical Engineer, (Foreign Dept.) General Electric Co., residence, Edison Hotel, Schenectady, N. Y.	Ernst Berg. C. P. Steinmetz. A. L. Rohrer.
Osborne, Marshall	Engineer in charge of Contracts,The British Thomson-Houston Co., 83 Cannon St., London, Eng.	H. F. Parshall. H. M. Hobart. Ralph W. Pope.
Slichter, Walter I.	Electrical Engineer, General Electric Co., residence, 234 Union St., Schenectady, N.Y.	C. P. Steinmetz. Ernst Berg. A. H. Armstrong.
Somellera, Gabriel F.	Partner, Salcedo & Co., Apartado 115, Mexico City, Mexico.	C. F. Beames. J. H. Shearer. P. H. Evans.
Steele, Walter D.	Electrical Engineer Public Light Commission, The City of Detroit, 40 Atwater St., E. Detroit, Mich.	Alex Dow. E. P. Warner. Jesse M. Smith.
Varley, Richard Jr.,	President, the Varley Duplex Magnet Co., 138 7th Street, Jersey City, residence, Englewood, N. J.	Townsend Wolcott E. A. Colby. H. Laws Webb.
de Waal Wm. H.	Engineer, Accumulator M'f'g Co., Cadena, No. 3, Mexico City, Mexico.	C. F. Beames. P. H. Evans. M. T. Thompson.

The following associate members were transferred to full membership:

Approved by Board of Examiners, March 9th, 1900.

William S. Aldrich	Professor of Electrical Engineering, University of Illinois, Urbana, Ill.
Harold B. Smith	Professor of Electrical Engineering, Worcester Polytechnic Institute, Worcester, Mass.

The Chairman:—It is very encouraging to see the growth of the Institute and note the spreading of its membership, not only through the United States, but even in the foreign countries of both hemispheres.

The next topic in order is the reading of a paper on "Hysteresis in Sheet Iron and Steel," by Arthur Hillyer Ford, to whom I give the floor.

A paper presented at the 142nd Meeting of the American Institute of Electrical Engineers, New York, April 25th. 1900. Manager Steinmetz in the Chair.

HYSTERESIS IN SHEET IRON AND STEEL.

BY ARTHUR HILLYER FORD.

Since the general introduction of stations for the supply of light and power, by the use of alternating currents, the subject of hysteresis loss in iron has been an important study from the standpoint of the efficiency of such installations. In the direct current system the only place where hysteresis loss occurs is in the armatures of the dynamos and motors; while the alternating current system has in addition the loss in transformer cores, which is apt to be larger than all other electrical losses combined, in the case of a station operating 24 hours per day. Therefore a slight increase in this loss may make a decided difference in the efficiency. Take as an example a two K.W. transformer having a copper loss of 56 watts and an iron loss of 42 watts which gives a maximum efficiency of 95.2% and an all-day efficiency of 86.7% on a basis of full load for four hours and the remainder of the time no load. If the iron loss is increased 20% the efficiencies become 95.0% and 84.8%

During the latter part of 1894, attention was called to the fact that there is an increase in the core loss (hysteresis and eddy current) of a transformer, or that the iron aged with use, in a letter by G. W. Partridge[1] to the *London Electrician*. This called forth a communication from J. A. Fleming,[2] citing similar observations which had been made in 1892. This aging was first

1. "Increase of Open Circuit Loss in Transformers with Time." *Electrician* (London) Vol. 34, p. 161.

2. "Time Increase of the Open Circuit Loss in Transformers." *Ibid*, Vol. 34, p. 190.

thought to be due to magnetic fatigue, but is has been shown by O. T. Blathy,[3] W. M. Mordey,[4] J. A. Ewing,[5] and others to be purely a heat effect.

The method used by Ewing was to subject the iron to rapid reversals of magnetism, at the same time keeping it cool, when no increase of the hysteresis loss was noticed. That used by Mordey was to make two cores from the same sample of iron and heat one to a given temperature by magnetic reversals and the other to the same temperature from some external source. On measuring the hysteresis loss it was found to increase at the same rate in both cores, thus showing that this increase is a pure heat effect. This method has been used by others, who took iron cores and found no aging when they were subjected to an alternating magnetic field and kept cool, but on allowing them to get hot, there was an immediate increase in the hysteresis loss.

Up to the present time there have been no tests published which throw any light on the cause of the increase of this loss.

This research was undertaken for the purpose of discovering if possible what the cause of this effect is, in order to find how it may be reduced. That it may be reduced seems probable to everyone who has studied the subject, for there are some irons which show this effect very slightly. Experiments have been carried out in a similar direction by F. Guilbert[6] which tend to show that chemical composition has no appreciable effect on the hysteresis loss in soft sheet iron.

This research is divided into two parts. I.—That on commercial transformers, which was undertaken with the object of showing the magnitude of the aging under conditions met in practice. II.—That on small specimens of iron obtained from various makers and users.

Thanks are extended to the various companies who furnished the iron and transformers for this series of tests and to those who made the chemical analyses.

3. *Electrician* (London), Vol. 34, p. 191.

4. "On Slow Changes in the Permeability of Iron." *Ibid*, Vol. 34, p. 249.

5. "Is the Magnetic Quality of Iron Affected by often Repeated Reversals?" *Ibid* Vol. 34, p. 297.

6. "On the Law of Hysteresis." *L'Eclairage Electrique*, Vol. 6, pp. 357, 390.

I.—Measurement of the Core Losses of Eight Transformers to Show the Magnitude of the Aging Effect.

These transformers were all obtained between June 1894 and October 1896 and had been used none, or for a few hours only, for testing purposes in the laboratory. They were connected with the high pressure coil of one, feeding the high pressure coil of the next, whose low pressure coil fed the low pressure coil of

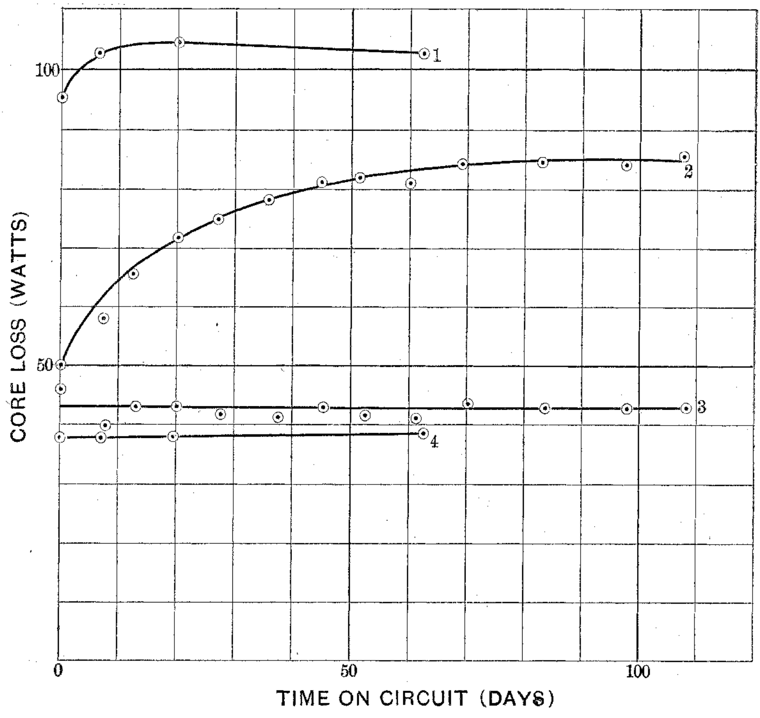

Fig. 1.

the third, and so on, with a lamp load on the low pressure coil of the last transformers. By requiring the large transformers to supply lamps, in addition to the power for the smaller ones, the load on each was made about two-thirds of its rated capacity and was kept on continuously with the exception of a few hours each week while the station was shut down.

The transformer capacities and the increase in the core losses are shown in Table I, and Figs. 1 and 2.

TABLE I.

No.	Capacity.	Increase in Core Loss.
1	1.5 K.W	25%
2	1.5 "	95%
3	1.5 "	2%
4	1.5 "	4%
5	1.25 "	113%
6	2.5 "	38%
7	1.5 "	20%
8	1. "	10%

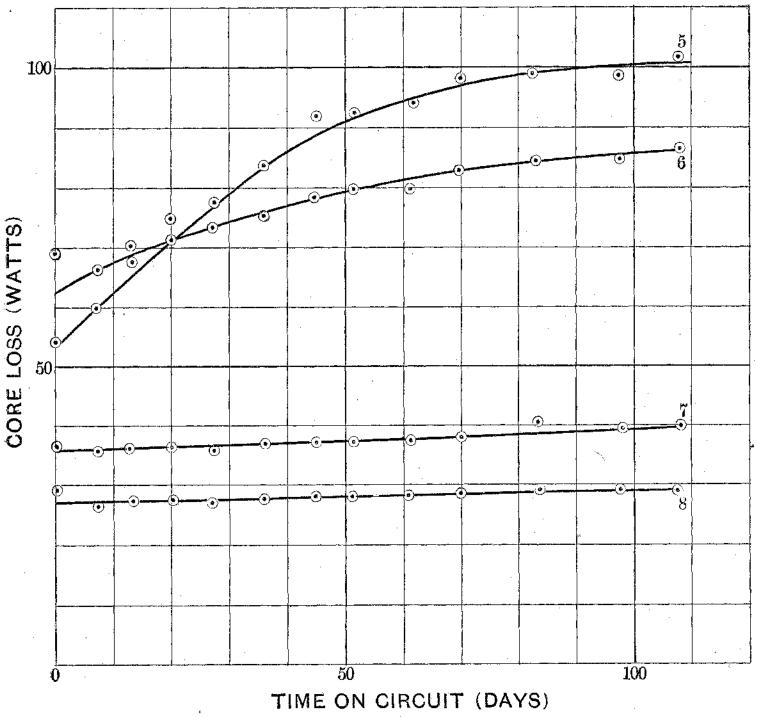

FIG. 2.

The first value of the core loss is high because it was made while the transformers were at the temperature of the room, while the other readings were taken while they were hot. In calculating the increase in the loss, the results of a previous core-loss measurement were used in order to get the total aging; for a slight increase was noticed on account of the use noted previously. It is to be noted that while the increase is in the hysteresis loss, the results are given for the total loss which will make the percentage increase of the hysteresis loss somewhat greater.

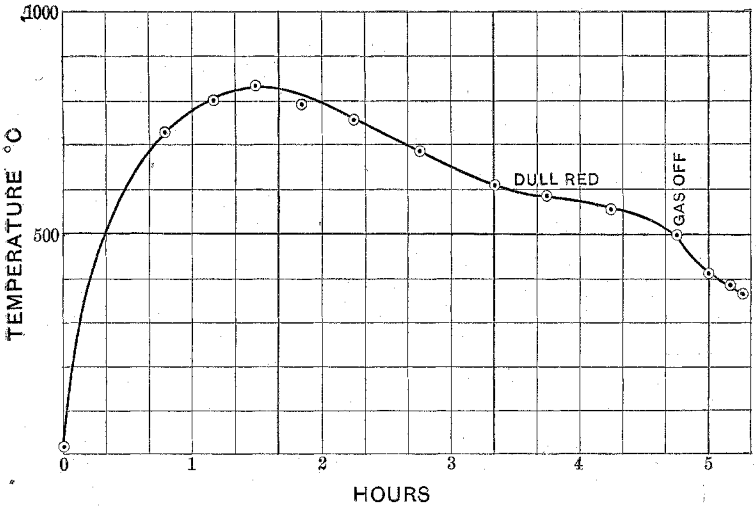
1000
500
TEMPERATURE °C
DULL RED
GAS OFF
0
1
2
3
4
5
HOURS

FIG. 3.

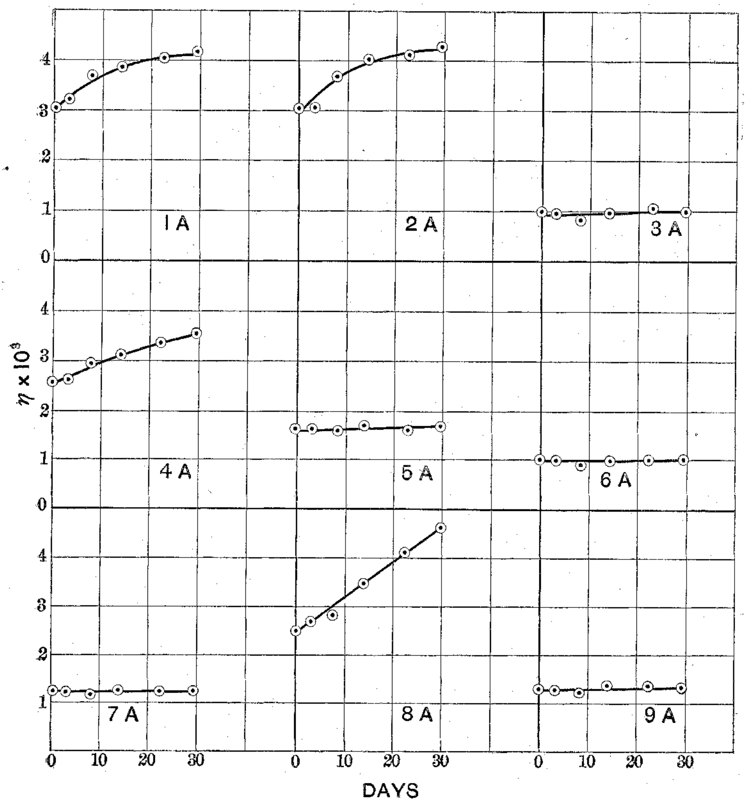
η x 10³
1 A
2 A
3 A
4 A
5 A
6 A
7 A
8 A
9 A
0
10
20
30
DAYS

FIG. 4.

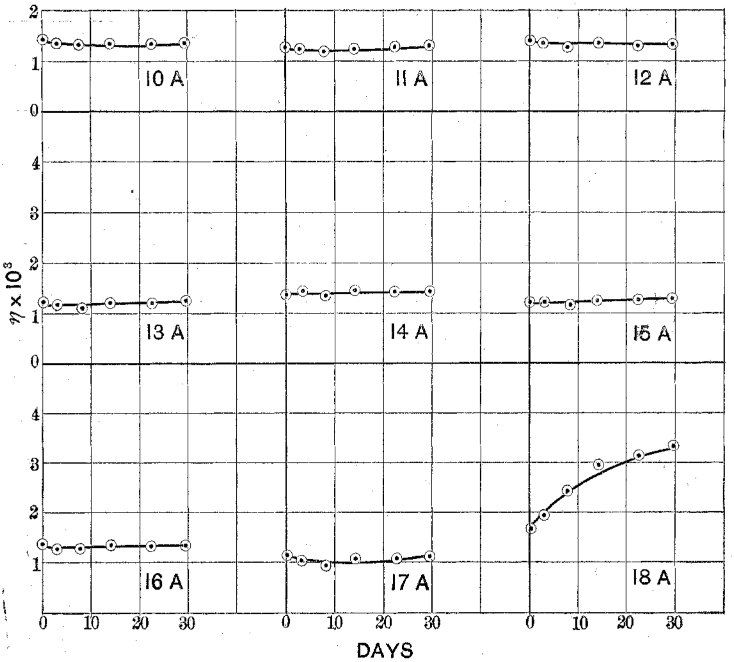
10 A
11 A
12 A
13 A
14 A
15 A
16 A
17 A
18 A
η x 10³
DAYS

FIG. 5.

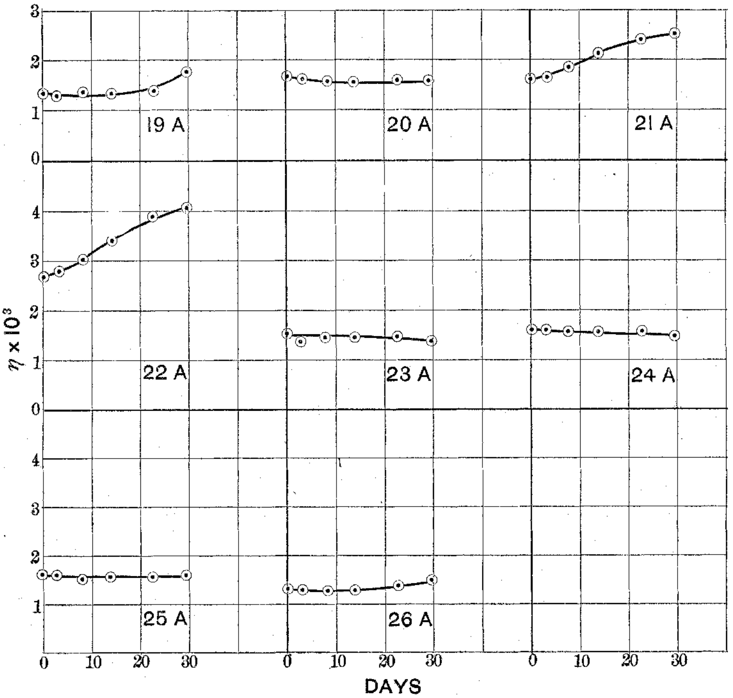
19 A
20 A
21 A
22 A
23 A
24 A
25 A
26 A
η x 10³
DAYS

FIG. 6.

II.—Test of the Hysteresis Loss of Small Samples.

Heat Treatment.—The samples were subjected to four different heat treatments which will be designated A, B, C, and D throughout this paper. Samples A, B, and C were heated in a gas muffle to a temperature of 835° C. taking 1.5 hours, and then allowed to cool slowly as the muffle cooled, taking 3.75 hours to cool to a temperature of 365° C. when the gas was shut off. Samples D

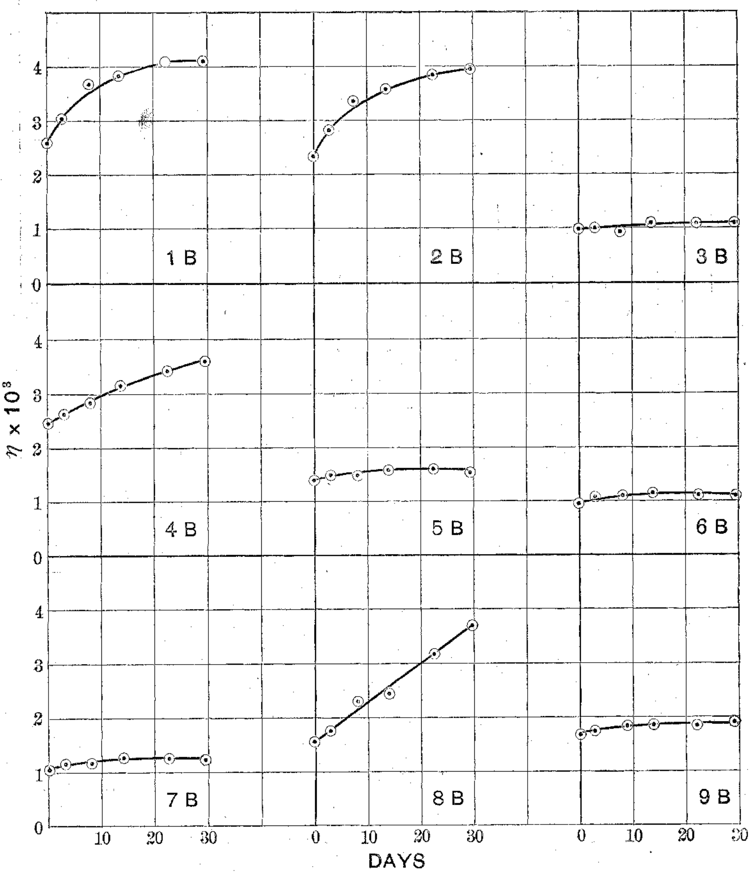

Fig. 7.

were taken out of the muffle during the heating, when a temperature of 804° C. was reached, and quenched in water at a temperature of about 15° C. Samples B and C were heated with the muffle the next day after being annealed. When a temperature of 205° C. was reached after heating one-half hour, samples B were taken out and quenched. After one hour, when a temperature of 400° C. was reached, samples C were quenched.

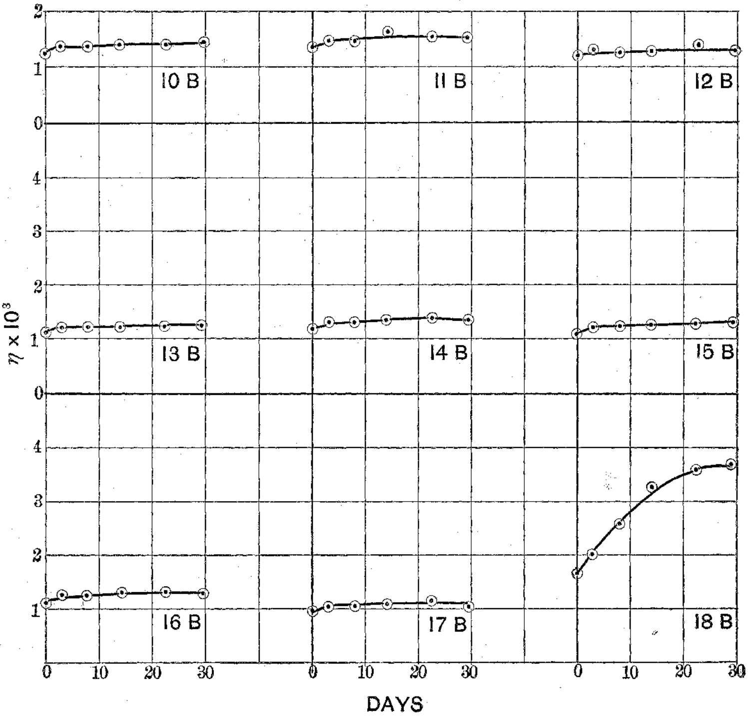
η × 10³
10 B
11 B
12 B
13 B
14 B
15 B
16 B
17 B
18 B
DAYS

Fig. 8.

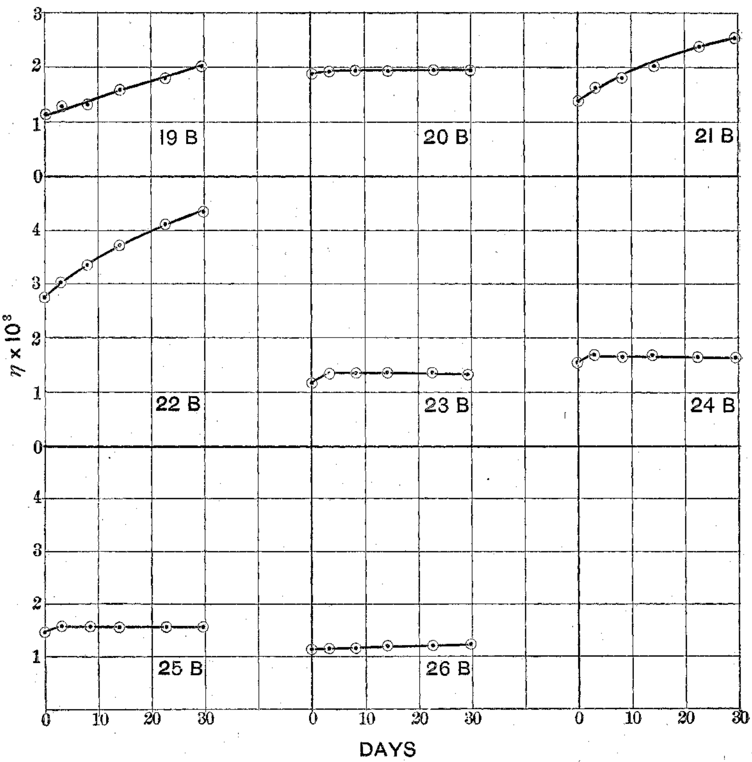
η × 10³
19 B
20 B
21 B
22 B
23 B
24 B
25 B
26 B
DAYS

Fig. 9.

The temperature of the gas muffle used for annealing was measured by means of a resistance pyrometer using a platinum wire having a resistance of 14.78 ohms at 0° C. and 18.64 ohms at 100° C. The temperature is deduced from the resistance of the pyrometer by means of the following formula.[7]

$$t = 100\,\frac{R_t - R_0}{R_1 - R_0} - \delta\left[\left(\frac{t}{100}\right)^2 - \frac{t}{100}\right]$$

For commercial platinum

$$\delta = 1.57 + 15\left(1.3383 - \frac{R_1}{R_0}\right)$$

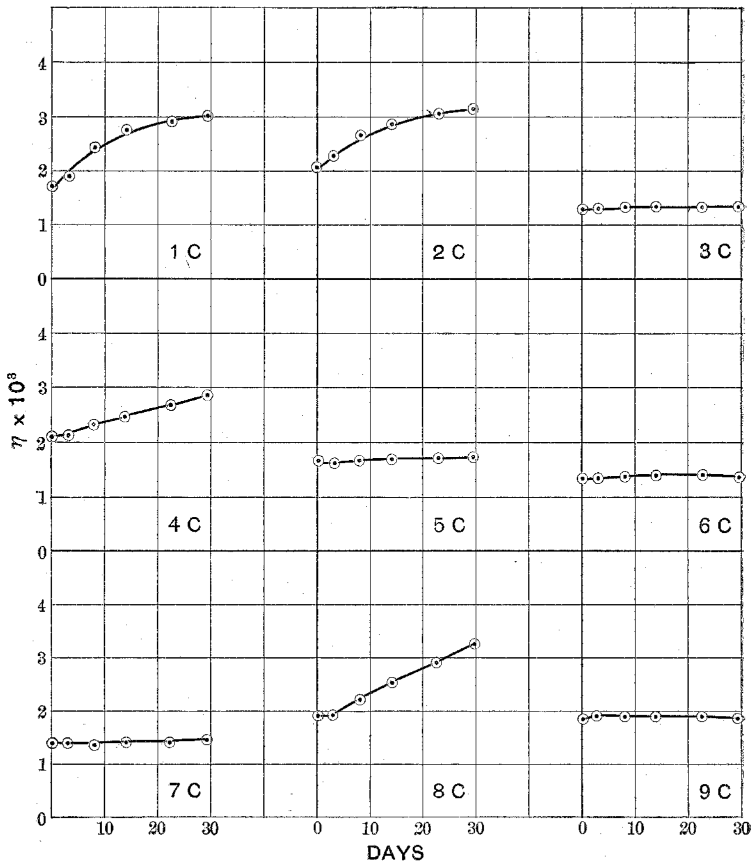

FIG. 10.

where t is the temperature and R_0, R_1 and R_t are the resistances at the temperatures 0°, 100° and t° C respectively. Values were assigned to t, the equation solved for R_t, and the results plotted in a curve showing the relation of t to R_t, from which the tem-

7. "On the Practical Measurement of Temperature." H. B. Collander. *Phil. Trans. Royal Soc.* of London. Vol. 178, p. 161.

perature of the muffle was obtained from the known resistance of the pyrometer.

The relation of the temperature to the time during the first heating and cooling is shown in Fig. 3.

After tying up the specimens in shape for measuring their hysteresis loss, they were placed in a box which had an average temperature of 60° C, with a variation of about 5° C each way, and kept there for a period of 29.5 days; their hysteresis loss being measured from time to time.

Measurement of Hysteresis Loss.—The hysteresis loss was measured in all cases by means of a Ewing hysteresis meter.[8]

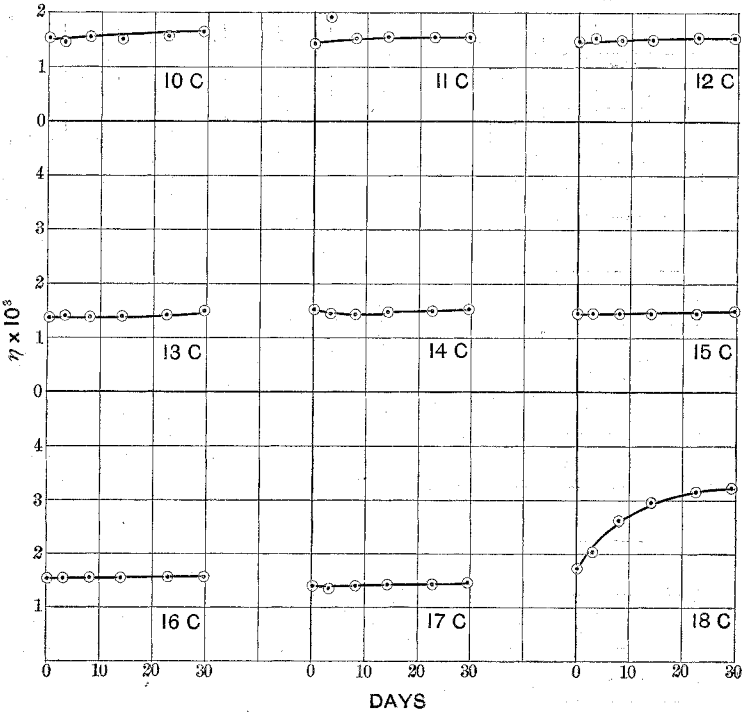

FIG. 11.

This instrument gives comparative values only and therefore requires calibration, for each set of measurements, by the insertion of two standard samples. These samples are sent with the instrument and their hysteresis loss as given is assumed to be correct. Results obtained with this instrument are likely to be in error as much as 3%, consequently two specimens of each sample

8. "A Magnetic Tester for Measuring Hysteresis in Sheet Iron." *Electrical Engineer*, (London). Vol. 29, p. 437.

were taken and the mean value of their hysteresis loss was used in plotting the curves and computing all results.

The hysteresis loss was measured six times during the 29.5 days that the specimens were kept hot. Owing to difficulties due to imperfect heating apparatus and the necessity of allowing the specimens to cool while their hysteresis loss was being measured,

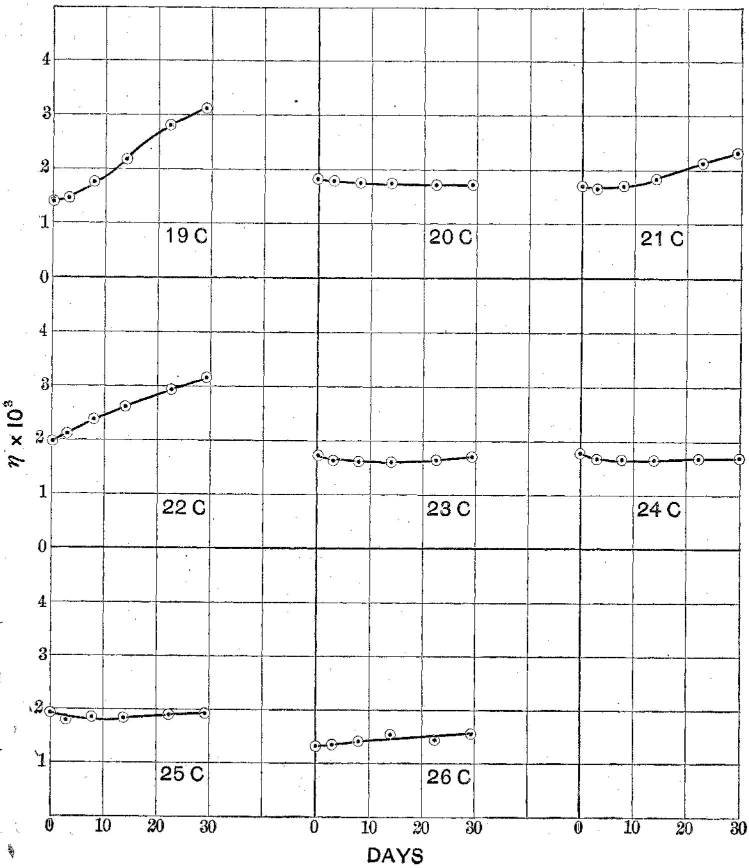

FIG. 12.

the heating was not continuous; but was interrupted for several hours at various times.

A preliminary test of 15 days, which is designated by the letter E, was made on the samples as received. The temperature for this test was 80° C, which was reduced to 60° C for the final test because after correspondence with transformer manufacturers the former temperature was thought to be too much above that normally found in good transformers.

The results of the tests are shown in Table II, and Figs. 4 to 18 inclusive, and are given in terms of Steinmetz's hysteresis constant obtained from the equation $H = \eta B^{1.6}$. H is the hysteresis loss in ergs per cu. cm. per cycle; η the hysteresis constant;

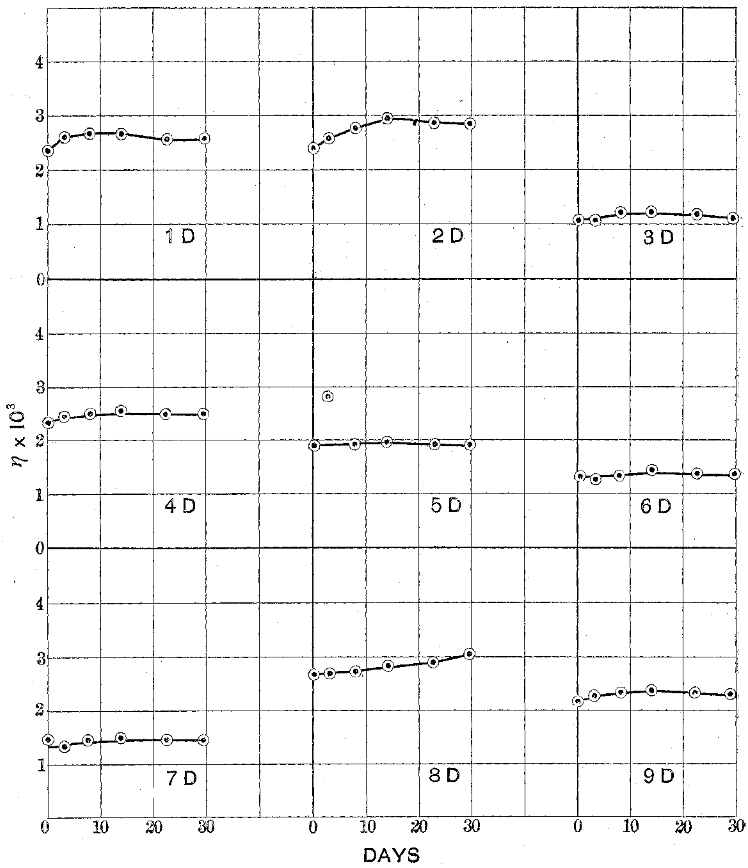

FIG. 13.

and B the magnetic density in gausses. For convenience in writing, the constant is multiplied by 10^3 in the results.

Chemical Composition.—The samples were analyzed to find the amount of silicon, phosphorous, manganese, sulphur and combined carbon which they contained. Table IV shows the results of this analysis.

TABLE III.

Initial Hysteresis Constant × 10^3.

Heat Treatment.

No.	A.	B.	C.	D.	E.
1	3.05	2.60	1.70	2.35	1.72
2	3.03	2.35	2.10	2.40	3.24
3	.96	1.00	1.32	1.05	.90
4	2.55	2.45	2.15	2.40	3.24
5	1.58	1.45	1.68	1.92	1.87
6	.98	.93	1.30	1.25	.98
7	1.22	1.08	1.38	1.40	1.21
8	2.45	1.60	1.90	2 68	4.39
9	1.30	1.70	1.90	2.20	2.01
10	1.40	1.35	1.57	1.75	1.43
11	1.22	1.40	1.46	1.40	1.43
12	1.34	1.30	1.45	1.50	1.31
13	1.18	1.25	1.40	1.35	1.35
14	1.40	1.25	1.45	1.50	1.33
15	1.18	1.15	1.45	1.50	1.16
16	1.30	1.20	1.50	1.50	1.47
17	1.02	1.00	1.40	1.43	1.14
18	1.65	1.62	1.75	1.85	2.33
19	1.35	1.20	1.40	1.55	1.53
20	1.62	1.92	1.80	3.08	3.26
21	1.70	1.40	1.65	1.75	1.95
22	2.75	2.70	2.00	2.40	3.53
23	1.38	1.35	1.65	1.30	
24	1.60	1.65	1.68	1.30	
25	1.54	1.52	1.85	1.95	
26	1.30	1.15	1.45	1.35	

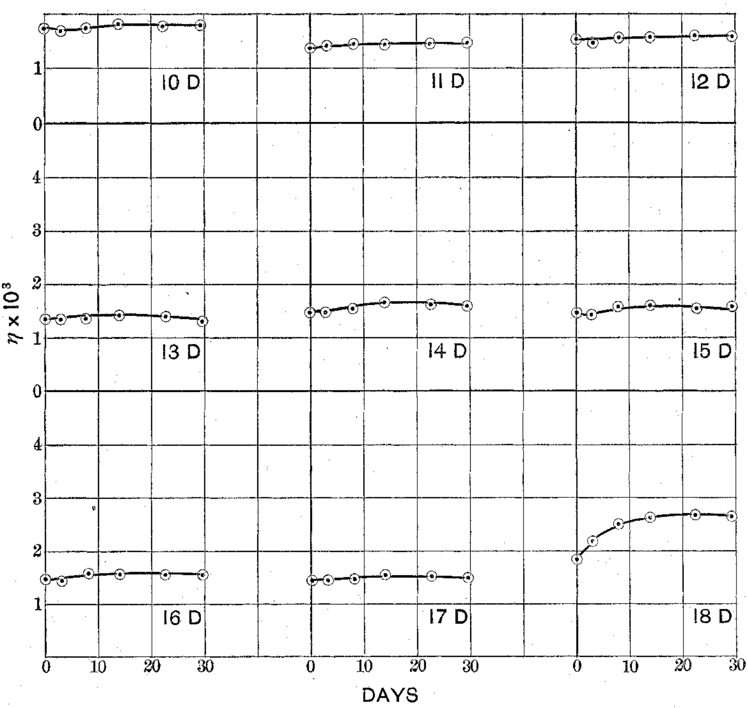

Fig. 14.

TABLE III.
Final Hysteresis Constant × 10^3.
Heat Treatment.

No.	A.	B.	C.	D.	E.
1	4.15	4.12	3.05	2.57	3.52
2	4.21	3.94	3.18	2.84	4.12
3	.99	1.09	1.37	1.15	1.02
4	3.54	3.61	2.88	2.51	3.90
5	1.69	1.54	1.74	1.91	1.86
6	1.03	1.10	1.39	1.31	.98
7	1.29	1.21	1.44	1.42	1.28
8	4.50	3.71	3.26	3.08	4.51
9	1.38	1.92	1.89	2.32	1.95
10	3.36	1.48	1.65	1.81	1.59
11	1.26	1.49	1.53	1.44	1.42
12	1.41	1.26	1.54	1.56	1.31
13	1.23	1.26	1.50	1.35	1.25
14	1.40	1.32	1.57	1.60	1.30
15	1.25	1.26	1.51	1.60	1.15
16	1.36	1.31	1.59	1.55	1.56
17	1.22	1.04	1.48	1.50	1.15
18	3.43	3.71	3.25	2.65	3.01
19	1.76	2.09	3.13	2.15	2.74
20	1.49	1.98	1.71	3.22	3.26
21	2.64	2 57	2.31	2.32	2.74
22	4.15	4.35	3.20	2.95	4.39
23	1.43	1.32	1.70	1.86	
24	1.41	1.65	1.70	1.81	
25	1.60	1.61	1.93	2.00	
26	1.44	1.26	1.56	1.38	

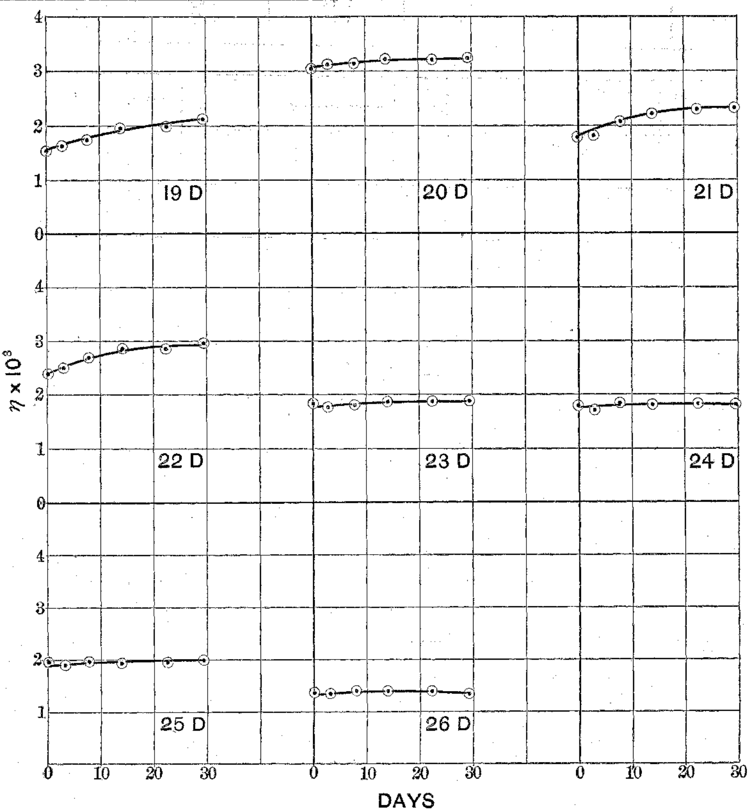

Fig. 15.

TABLE III.

Increase in Hysteresis Constant % After 29.5 Days at 60° C.

Heat Treatment.

No.	A.	B.	C.	D.	E.
1	36	58	79	9	105
2	39	68	51	18	27
3	3	9	4	9	13
4	39	47	34	5	13
5	7	6	4	—1	—1
6	5	18	7	5	0
7	3	12	4	1	6
8	84	132	71	15	3
9	6	13	—1	5	—3
10	140	10	5	4	11
11	3	6	5	3	—1
12	5	—3	6	4	0
13	4	1	7	0	—7
14	0	6	8	7	—2
15	6	10	4	7	—1
16	5	9	6	3	6
17	20	4	6	—5	1
18	108	130	86	43	29
19	30	74	123	38	79
20	—8	3	—5	5	0
21	55	83	40	33	40
22	51	61	60	23	24
23	4	—2	3	43	
24	—12	0	1	39	
25	4	6	4	—3	
26	11	10	8	2	

TABLE IV.

Impurities in Iron Sample %.

No.		Si.	P.	Mn.	S.	C. C.
1	Swede Iron	Trace	.028	Trace	.02	.05
2		.066	.120	.16	.05	.05
3	Open hearth steel	Trace	.027	.30	.05	.06
4		.056	.125	.33	.025	.06
5	Steel	Trace	.105	.44	.02	.06
6		"	.059	.27	.02	.05
7		"	.090	.36	.03	.05
8	Bessemer steel	"	.089	.42	03	.08
9		"	.093	.47	.02	.07
10		.028	.089	.25	.025	.05
11		Trace	.056	.38	.03	.05
12	Steel	.017	.071	.37	.018	.10
13	"	.020	.073	.41	.025	.10
14	"	.020	.076	.29	.030	.10
15	"	.016	.060	.37	.02	.10
16		Trace	.023	.52	.05	.07
17		.006	.075	.43	.03	.07
18	Iron	.048	.210	.10	.02	.06
19	Bessemer Steel	Trace	.102	.39	.06	.05
20	" "	.009	.064	.39	.02	.09
21		Trace	.093	.30	.07	.06
22		.040	.085	.34	.02	.07
23		Trace	.099	.36	.03	.07
24		"	.071	.34	.02	.05
25		"	.074	.27	.02	.09
26		"	.101	.26	.03	.05

Discussion of Results.

In order to make the relation, if one exists, between the hysteresis phenomena and the impurities in the iron clearer, three sets of results were plotted. These show the relation between (1.) the various impurities, taken one at a time, and the initial hysteresis constant; (2.) the various impurities, taken one at a

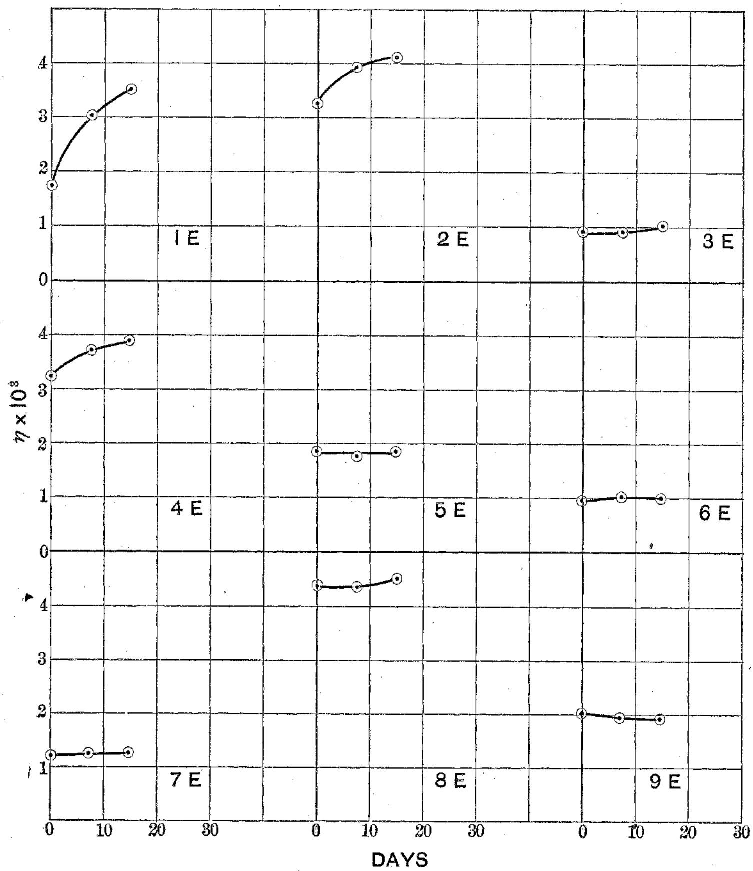

Fig. 16.

time, and the increase in the hysteresis constant; and (3.) the various impurities taken two at a time and the final hysteresis constant. Samples of these results as plotted are shown in Figs. 19 to 21 inclusive. The relation between the final hysteresis constant and the sum of the impurities was also plotted, Fig. 22.

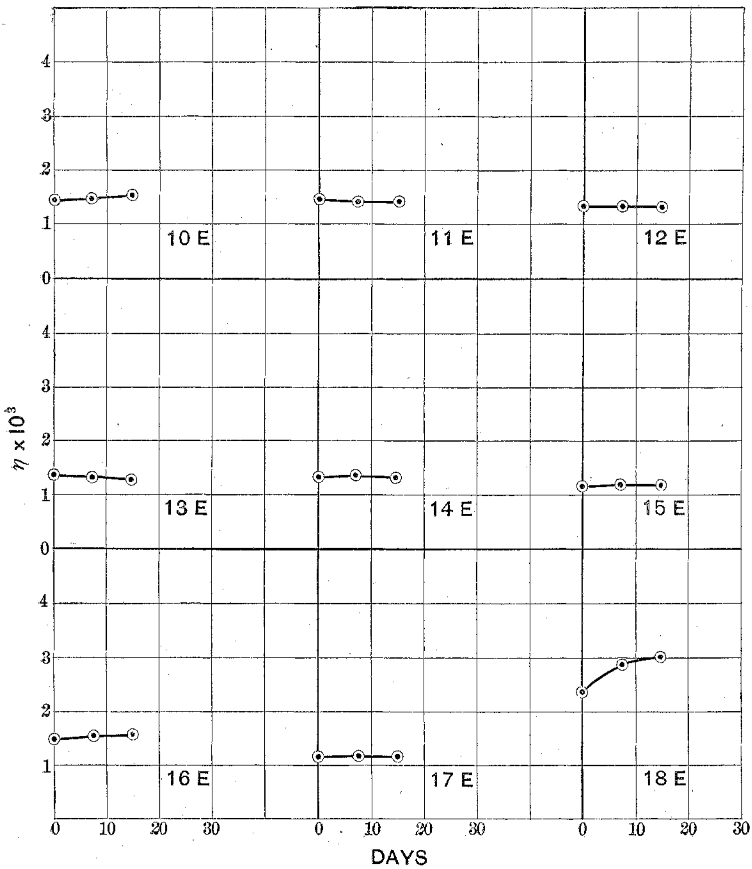
η x 10³
4
3
2
1
0
10 E
11 E
12 E
13 E
14 E
15 E
16 E
17 E
18 E
0
10
20
30
DAYS

FIG. 17.

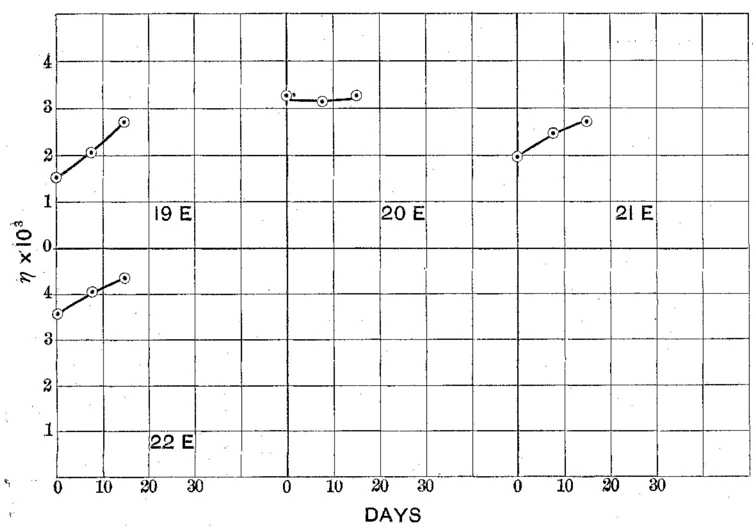
η x 10³
4
3
2
1
0
19 E
20 E
21 E
22 E
0
10
20
30
DAYS

FIG. 18.

From an inspection of these results it is evident that neither a single impurity nor pair of impurities has any preponderating effect on either the absolute value or the increase in value of the hysteresis constant. Specimens No. 7 and No. 8 have practically the same chemical composition but differ widely as to hysteresis constant and aging.

A comparison of the constants after the different heat treatments shows that the structural difference which probably causes

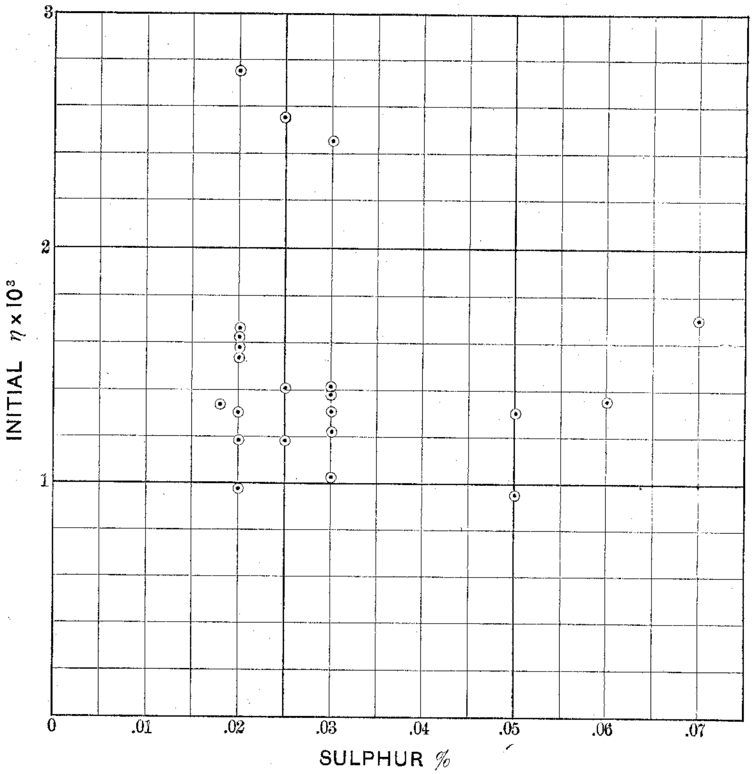

Fig. 19.

the difference in the hysteresis phenomena is not materially affected by annealing or quenching if the temperature is below 850° C. It is noticed that specimens, Nos. 1, 4, 8, 18, 21 and 22 have their final hysteresis constant reduced by quenching from a red heat; but no cause for this is to be found in their chemical composition. Most of the samples show less effect of aging for the specimens which have been quenched from a red heat, which is probably due to the iron being in a more rigid state after such treatment and consequently allowing less change to take place at the comparatively low temperature of 60° C.

The best sample tested is No. 3 which is of open hearth steel and is nearly equaled by Nos. 6 and 7 of which the process of working is unknown.

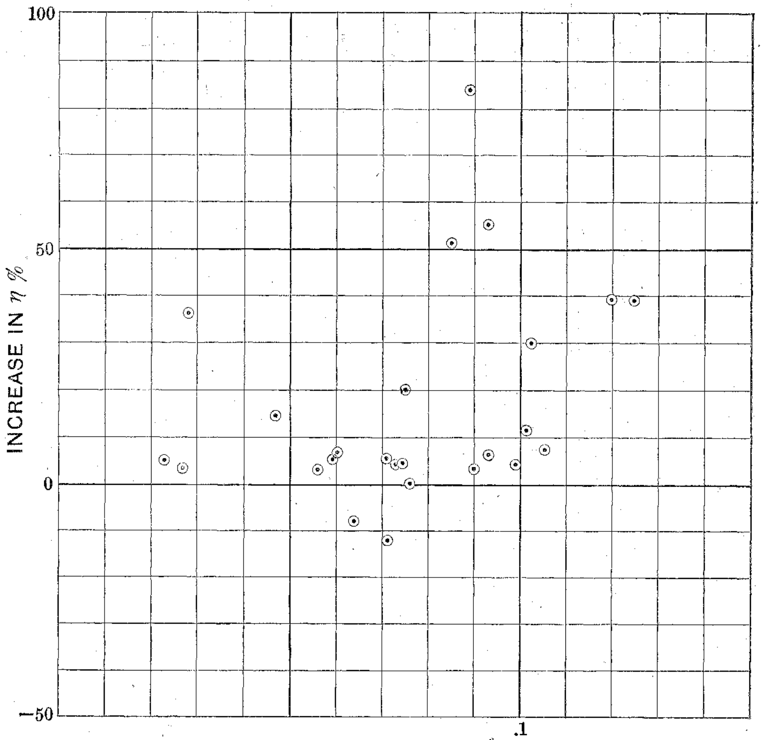

FIG. 20.

By an inspection of the curves showing the relation between the hysteresis constant and time, it is seen that several of the samples show an increase and then a decrease in the hysteresis constant; as is shown more plainly when the iron is kept at a higher temperature.[9]

CONCLUSION.

The conclusion to be drawn from this research is that the hysteresis constant for iron as pure as the samples tested is not so much dependent upon the chemical composition as upon the physical structure of the material due to the method of working.

9. "Effects of Prolonged Heating on the Magnetic Properties of Iron." S. R. Roget, *Electrician*, (London), Vol. 41, p. 182.

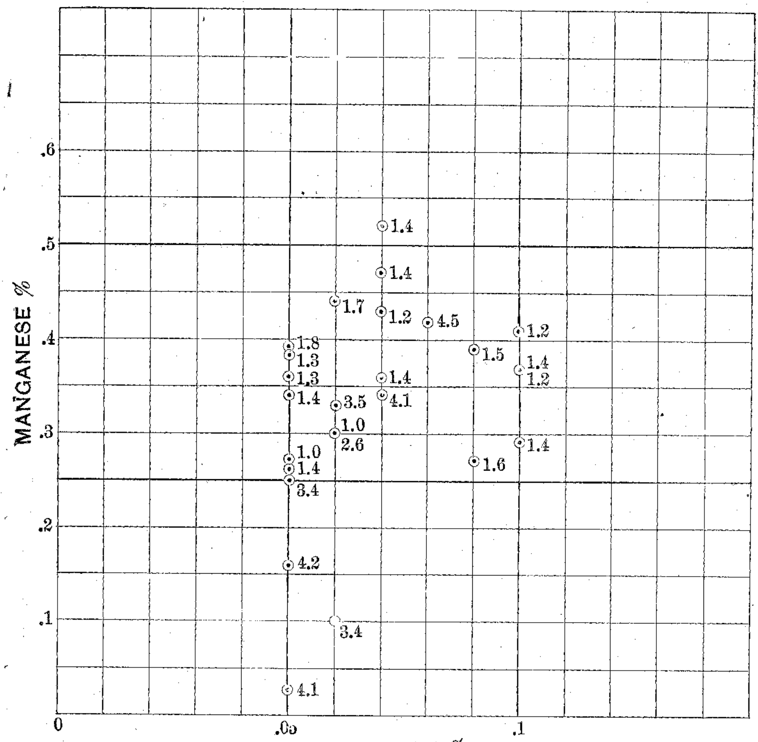

Fig. 21.

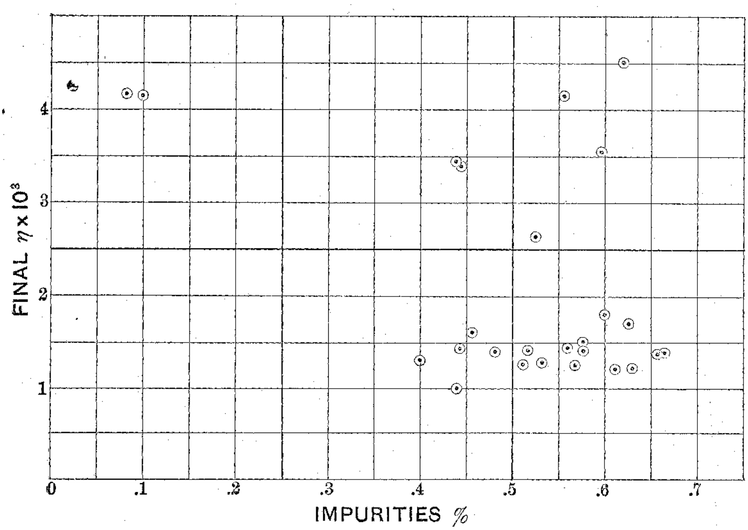

Fig. 22.

The most hopeful direction for future research in this subject seems to be by watching the metal in all stages of its manufacture and studying its microscopic structure.

Discussion.

Mr. Ford:—I might say a few words about the origin of these samples. At first I started out to make separate tests of samples cut with their length parallel to the length of the sheet, and samples cut crosswise of the sheet and found that there was some difference in the hysteresis, but owing to the tediousness of making the tests, part of these were thrown out, so that all the samples represented in this paper are samples of different kinds of iron. There may be in some cases iron of two or more thicknesses obtained from one manufacturer. The majority of the specimens were obtained from transformer manufacturers, though some were obtained directly from the iron makers. Some attempt was made to get the method of working the iron, but as you will see from the table this was not entirely successful.

The Chairman:—We have listened to a very interesting paper, and discussion is now in order. Before beginning the discussion, however, I would like to ask the author a question for information and explanation. If I understand right, Table III gives the hysteresis constant of iron which has been annealed and then quenched in water. Starting from different temperatures, in the first part of Table III it gives the hysteresis constant after this heat treatment; the second part gives hysteresis constant after additional treatment, and the third part gives increase of hysteresis constant. I do not find, however, the original hysteresis constant before the heat treatment has already been taken.

Mr. Ford:—In Table III., column E, you will find the results of a preliminary test made on the samples as received. The only treatment which these samples had received was a slight heating due to the action of the shears in cutting the samples and that due to filing the ends. The samples were placed in a hardened steel clamp and filed to an exact length, which, of course, heated them considerably.

Dr. Samuel Sheldon:—In Part II. of this paper we have a description of how over a hundred samples of sheet iron or steel have been subjected to various heat treatments, and how the hysteresis losses and the hysteretic constants have been measured for each of these samples after the various treatments. As a result, there has been found either quite a noticeable increase in the value of the hysteretic constant due to the treatment, or very little change at all; in the latter case either a little decrease in the hysteretic constant or a slight increase. The different heat treatments seem to show no like effect on the different samples. It is pertinent to ask what the heat has done to increase the hysteretic constant in those cases where it has noticeably increased it. Transformer sheet irons, like all rolled metals, are allotropic as regards density. In the direction of the length of the sheet there is less density than there is in a direction at right angles to that of rolling. Sheet iron, in order to have a small hysteretic constant, should be least dense in the direction of magnetization and most dense along the magnetic equipotential surfaces. Now in this case, as was mentioned by the author, after the conclusion of the paper, there was no regular rule followed as to the cutting out of the samples from the sheet. The samples, which were cut out to fit, as I understand it, Ewing's hysteresis measurer, are quite a good deal longer than they are wide, being three inches long and about half an inch wide. In those cases where the length of the sample was along the direction of the drawing out of the plates, or in the direction of the least density, heating would cause a rise in the hysteretic constant. This is because a lessening of the density in a direction at right angles to the magnetic flux has the same effect as an increase of density in the direction of the magnetic flux. Compacted bodies which have been passed through rolls, when afterward subjected to heat, increase in size in a direction at right angles to the direction of rolling and the increase is a permanent increase. This was called to my attention first, I think, in connection with some brass binding-posts, whose perfectly fitted screws were heated by a current passing through them. As a result they grew so large in diameter that they would but tightly fit their holes. They were turned down so as to fit loosely and they were again heated. Again they grew large enough to fill the holes. Under the application of heat, they grow and permanently keep a larger diameter. The mere heating of a sample of iron, which has just come from the rolls, would increase the hysteretic constant, if the magnetization were in the direction along which the strip had been pulled out from the rolls; it would increase it permanently. If, however, the magnetization were at right angles to the grain of the metal, the increase of size in the direction of the magnetization, due to heating, would decrease the hysteretic constant, and the accompanying increase of size in the direction which is at right angles with the previous direction and which is in the direction of the thickness of the plate would increase it to about the same extent. Now it seems to me that those samples, which upon test have shown no very marked increase or decrease, were cut out so that afterwards the magnetization was in a direction perpendicular to the grain; whereas those which have shown a marked increase in the hysteretic constant were cut so that the magnetization was in the direction of the grain.

Mr. Ford:—I would say in this connection that about the first fifteen samples, I believe, were those of which I had specimens cut both ways of the sheet, and, as I remember it, those which were tested finally were those in which the magnetization was parallel to the grain of the iron; but in the preliminary test, referred to in column E, no difference in the aging was noticed between those which were cut at right angles to the grain and those which were cut lengthwise of the grain.

A matter of interest in this connection is the effect of intense cold on the hysteresis constant. We usually consider that this is rather stable at or below atmospheric temperature; but such is not the case, as was shown by a simple experiment. Four specimens of sample No. 14 (steel) were taken, and by mixing the sheets of which they were composed their hysteresis constants were made equal.

Specimens cut side by side from the same sheet will have different constants, so that this shuffling was necessary in order to have the four samples the same. These samples having an initial hysteresis constant of .00124, were put in a beaker of liquid air having a temperature of, approximately, — 210° C., and allowed to stay there until thoroughly cool.

They were then taken out and put in the hysteresis tester and the constant determined while they were cold, and found to be .00159. After this they were warmed to the temperature of the room, about 20° C., and the constant found to be .00139, showing a permanent increase in the hysteresis constant of 12% and a temporary increase of 28%.

MR. STEINMETZ:—[The Secretary, in the Chair] This paper is very interesting in what it gives and what it does not give. It does not really give a solution of the problem, namely, why does iron age, and how can aging be avoided, nor does it give the reason why one sample of iron has a high hysteresis loss and the other a low hysteresis loss. It only shows again that the chemical constitution has nothing to do with the hysteresis, but that hysteresis loss depends largely on the physical constitution of the iron, and on the chemical constitution probably only indirectly in so far as the physical constitution depends on the chemical to a certain extent. That is, very pure iron probably is independent of the chemical constitution, but as 1% or 2% of carbon gets in, you will find entirely different values of hysteresis constant because you find entirely different physical constitution. You find this in brittle cast iron for instance. There is one feature which strikes me in all these tables: that is these very low values of the hysteresis constant, some going down below 1. Now these are values very much lower than I have found, and I am very suspicious that the absolute values are not correct. I should rather suspect, and believe we have reason to suspect, from my knowledge of the instrument with which these tests were made that there is a constant error in all the readings, which makes them less than they should be. This does not impair the value of the paper, but merely means that we cannot rely on these measurements. Referring to Table III. the lowest of which I have absolute record is 1.24, and that was a very exceptionable case, and here are quite a number which go far below that. But there is one very interesting feature regarding this aging in the table giving the percentage of aging. That is, we do not find that the different kinds of iron age differently, but we do find that some iron does and other iron does not age, because you see there are hardly any intermediary values. All these values are very low values, all values of a few per cent., and a few per cent. we can hardly count upon as proving anything, because you must expect in different conditions on different days iron will vary a few per cent. or its physical structure change slightly. If you exclude small changes in the hysteresis values, changes of 5 or 6 per cent., we find that here about three-quarters probably of the samples of iron do not change noticeably, while the rest change by very large values. But that means that really there are two kinds of iron: that kind of iron that changes, ages considerably, and that kind of iron which does not change. These tables are very interesting, although for a different reason: namely, here samples of the same iron have been exposed to different treatment. First, hysteresis loss has been taken as they were received, then after annealing at 800° C., then after annealing and quenching at 200°, 400° and 800°. Now you compare the different values A, B, C, D, and E and you will find one interesting feature, that in most cases a minimum value of hysteresis constant occurs at B or C. Take for instance the first part of Table III., the first line, No. 1, the minimum is at C, you see, in No. 2 the minimum is again at C, No. 3 is an abnormally low value and does not agree with that. In No. 4 you find the minimum, at C. In No. 5 you find the minimum at B. That points to one feature, that there is a certain temperature of quenching at which the hysteresis constant reaches the minimum and that this temperature is as a rule between 200° and 400° C. That accords fairly with my experience that a certain temperature gives the minimum value of hysteresis loss, and if you go beyond that temperature you get higher values, and if you go below that temperature you get lower values again of hysteresis constant. The temperature in most of these tables here seems to have been 200° to 400° C. That is all that I can say about it. Perhaps I might suggest an explanation of this aging: that each sample of iron has a certain value of hysteresis constant at one temperature, a different value at another temperature. The hysteresis constant is a function of the temperature, and the physical constitution of the iron also a function of the temperature, and by maintaining the iron at this temperature for an infinitely long time it reaches this permanent value. Now by exposing the iron to a different temperature, either higher or lower, or by mechanically treating it, or in any way changing the physical constitution so that it does not correspond to what it would assume at a temperature of 60° C., then when we maintain it at 60° C. it gradually will change the physical constitution, the limiting value corresponding to the stable state of 60° C., and we will therefore probably find this aging which may, as some of these tests show, be negative. That is, the hysteresis constant may decrease, although as a rule it increases. It increases because the iron has been brought to this temperature from a higher temperature from annealing, and we know that as a rule the hysteresis constant as a function of the temperature decreases with increasing temperature of the iron. Raising the iron first to high temperature and producing the physical constitution corresponding to the high temperature, and then maintaining it at low temperature it will gradually increase in hysteresis loss until it assumes a value corresponding to this lower temperature. I do not know whether this explanation is correct, but some features seem to point to that. This gradual increase of hysteresis, for instance, with some kinds of iron and almost constancy in other kinds of iron: that is, increase, not uniform, but increase first fast and then slower and slower, seeming to tend to a constant value.

MR. I. A. TAYLOR:—I was interested in one point Mr. Steinmetz made, that some irons have an increase in their hysteresis loss and others do not. Several of the manufacturing companies have from time to time made claims that they supplied non-aging iron, but in trying to get stringent guarantees about a year ago, it was found that the best that could be done was to obtain a loss of less than about 10% aging per year for two years, which would seem as though, from a commercial standpoint at least, the non-aging variety is still rather difficult to obtain. However, as compared with some of the iron tested by Mr. Ford, 10% per year might be termed extremely non-aging.

It seems as though the more important result of aging has been overlooked—that while the increased all-day losses and the cost of supplying the same have received entire attention, they are really of little more than academic interest; but the fact that the temperature elevation increases in direct proportion to any increase in the total transformer loss, and therefore must increase on account of aging, not theoretically, but practically sufficient to make it impossible for a transformer to carry its rated load after it has been used a few years, is a much more important item.

It is only on this account that it is absolutely necessary commercially to keep the proportion of the iron loss to the total loss down to about 50% or thereabouts. If the iron loss could be raised without fear of dangerous increase due to aging, and the copper loss correspondingly lowered, the better non-inductive regulation would make it possible to use incandescent lamps of at least 15% better economy than are at present possible on alternating current lines. Certainly if transformers can be obtained which will not age practically, it will be a great advance in the interest of the alternating-current central station.

THE CHAIRMAN:—If there are no further remarks Mr. Ford will have an opportunity to close the discussion.

Mr. Ford:—In regard to what has been said about the hysteresis meter, I quite agree with Mr. Steinmetz in doubting the absolute value of these readings. Any one who has worked with a hysteresis meter knows that it is a very convenient apparatus to get comparative results with, but when it comes to absolute values it is quite difficult to calibrate. The samples which came with this hysteresis meter were from Prof. Ewing's laboratory and accompanied by a certificate signed by him, so that they are presumably correct. I might also state that the tests referred to under E in Table III. were obtained with another hysteresis meter. The ultimate calibration and comparison of these meters went back, however, to a certain pair of samples, but they were compared with other samples which were sent with another hysteresis meter, and the two sets of samples agreed quite closely.

The Chairman:—Before relinquishing the Chair, I wish to say that we have the privilege this evening of having with us one of our members from a very distant point, Mr. Peirce, of Johannesburg, where he is the leading electrical engineer of the Consolidated Gold Fields of South Africa, a part of the world that is now of unusual interest to all of us. Mr. Peirce found it necessary in October last to detach himself from the interests at Johannesburg and he is now in this country engaged in finding a solution to some very interesting electrical problems connected with the mines. Perhaps this evening some of the gentlemen present may be able to assist him in regard to any inquiries he may make.

Mr. A. W. K. Peirce:—Mr. Chairman and Gentlemen, I don't know that anything that I can say would be of particular interest. Perhaps, though, you might like to hear what has been done in electrical work in that country which Mr. Pope has referred to so feelingly. I have been out there about four years. At that time they were just beginning really to wake up to the possibilities of electrical power transmissions and other applications. Previous to that date their work had largely been lighting, and the only plants installed were small plants of all kinds, sizes and description and usually rather poor. I know I saw some machines there that carried me back to the very early days as I remember them. They consisted of a field frame and a pair of bearings and the armature, all supported on a timber bed-plate. The only connection between the bearings and the frame was a wooden bed-plate, and there were other freaks of that description. As I say, they have just begun to awake to the possibilities of electric power transmission, and now they use electric power quite extensively. There is one large company there that established a plant for the purpose of supplying power generally along the line. In the first place let me say that the central mining region there, the Witte Water Rand, occupies a stretch of country about 25 miles long and a few thousand feet