T H E S I S

EFFICIENCY AND REGULATION TESTS OF GENERAL ELECTRIC TRANSFORMER, TYPE H, #497204.

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J U N E 1 9 0 8

The static transformer is a device used for changing the voltage and current relations of an alternating current. It consists, essentially, of a pair of mutually inductive circuits called the primary and secondary coils, and a magnetic circuit interlinked with both coils. This magnetic circuit is called the core of the transformer.

The primary and secondary coils are so placed that the mutual induction between them is very great. Upon applying an alternating voltage to the primary coil, an alternating flux is set up in the iron core, and this alternating flux induces an E.M.F. in the secondary in direct proportion to the ratio of the number of turns of the primary to the secondary.

The primary is the coil upon which the E.M.F. from the line, or source of supply, is impressed, and the secondary is the coil within which an induced E.M.F. is generated. The magnetic core in transformers is composed of laminated sheets of steel or iron.

The type of transformer used in our testing work was the core type, in which the coils of wire surround a more or less elongated core of laminated iron. These iron stampings or plates are interleaved between one another, forming an imbricated joint. This method reduces the reluctance of the joints to a small value, thereby reducing the value of the current required to magnetize the core.

The windings are arranged as two concentric cylinders, with the secondary coil wound next to the core, and the primary wound upon the outside. The coils are then slipped upon the two laminated legs and the sheavings arranged to form one continuous circuit.

In a transformer the capacity for doing work increases directly as the volume of the material, densities and proportions remaining constant. The radiating surface increases with the square of the dimensions, and the volume increases as the cube of the dimensions. It is therefore evident that the capacity for work increases faster than the radiating surface. It is thus evident that since the losses in a transformer are in proportion to the volume, a point is reached in the design, where it is necessary to provide additional means of ventilation.

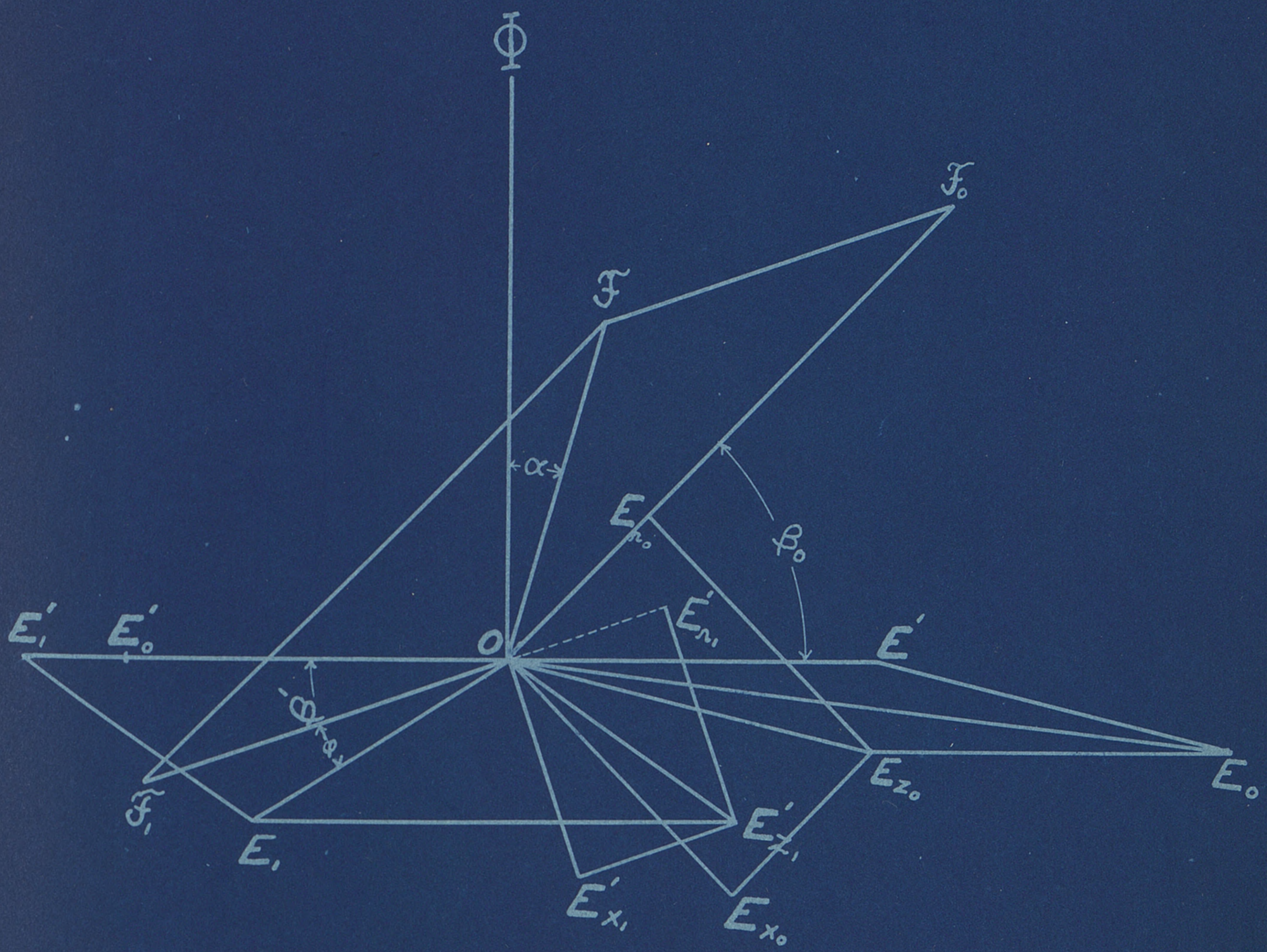
The method of ventilation adopted in transformer tested was by oil. Oil cooled transformers are those in which the coils and core are immersed in oil, the oil acting as a medium for conducting the heat from the coils to the surrounding medium. This oil in addition to acting as a heat conducting medium, also acts as an insulating medium, by increasing the break down resistance of the insulation. It also prevents the oxidization of the insulation. If a sufficient space is left inside the transformer case, the heated oil will rise and be cooled by contact with the transformer case, and then settle, causing a circulation and a consequent cooling of the coils.

An alternating current transformer may be regarded as a species of dynamo, in which neither armature or field-magnet revolves. Instead of revolving, the magnetism of the magnetic current is made to vary through rapidly repeated cycles of alternation by exciting it with a separate alternating current. The secondary coil of the transformer corresponds to the armature coil of a dynamo, while the primary coil of the transformer corresponds to the field coils of the dynamo.

If an alternating current having a frequency of f periods per second be sent through either of the coils, there will be set up in the other coil an alternating electromotive force having the same frequency f, because the iron core is undergoing a magnetization of the same frequency per second. The effect is the same as if the iron core was plunged into and removed from the secondary coil f times per second.

To calculate the electromotive force induced in a coil of any given number of turns by an alternating magnetic flux in the core within it, let S be the number of coils in the spiral, and N be maximum value of the core flux. Suppose that the variation of flux follows the sine law. The value of the flux at a time t after the maximum has occurred may be represented by Nt

$N_t =$ N Cos 2 f t. But the electromotive force in one turn is proportional to the rate at which the flux N changes, or $\frac{dN}{dt}$. To get the total induced electromotive force the value in each turn must be multiplied by S and divided by 10^8 to reduce the value to volts.



TRANSFORMER DIAGRAM.

T H E O R Y

Graphically the polar diagram of MMF_s of a transformer is constructed by Steinmetz as shown on preceding plate. Let o Φ = magnetic flux in intensity and phase (for convenience, as intensities, the effective values are used in this discussion) assuming its phase as the vertical; that is, counting the time from the moment where the rising magnetism passes its zero value.

Then the resultant M.M.F. is represented by the vector O F, leading o Φ by the angle F o Φ = ∞ The induced E.M.F.s have the phase 180°, that is, are plotted towards the left, and represented by the vectors OE'o and OE'_1

If now, B' = angle of lag in the secondary circuit, due to the total (internal and external) secondary reactance, the secondary reactance, the secondary current I_1 and hence the secondary M.M.F., $F_1 = n_1 I_1$, will lag behind E'_1 by an angle B', and have the phase 180°+ B', represented by the vector O F_1. Constructing a parallelogram of M.M.F.s with O F_1 as a diagonal, and O F_1 as one side, the other side or O Fo is the primary M.M.F., intensity and phase, and hence, dividing by the number of primary turns N_0, the primary current is $I_0 = \frac{F_0}{No}$.

To complete the diagram of E.M.F.s we have now:- In the primary circuit : E.M.F. consumed by resistance is $I_0 r_0$, in phase with I_0, and represented by the vector OE r_0.

E.M.F. consumed by reactance is $I_0 x_0$, 90° ahead of I_0, and represented by the vector OE x_0. E.M.F. consumed by induced E.M.F. is E'_0, equal and opposite to E'o, and represented by vector OE'.

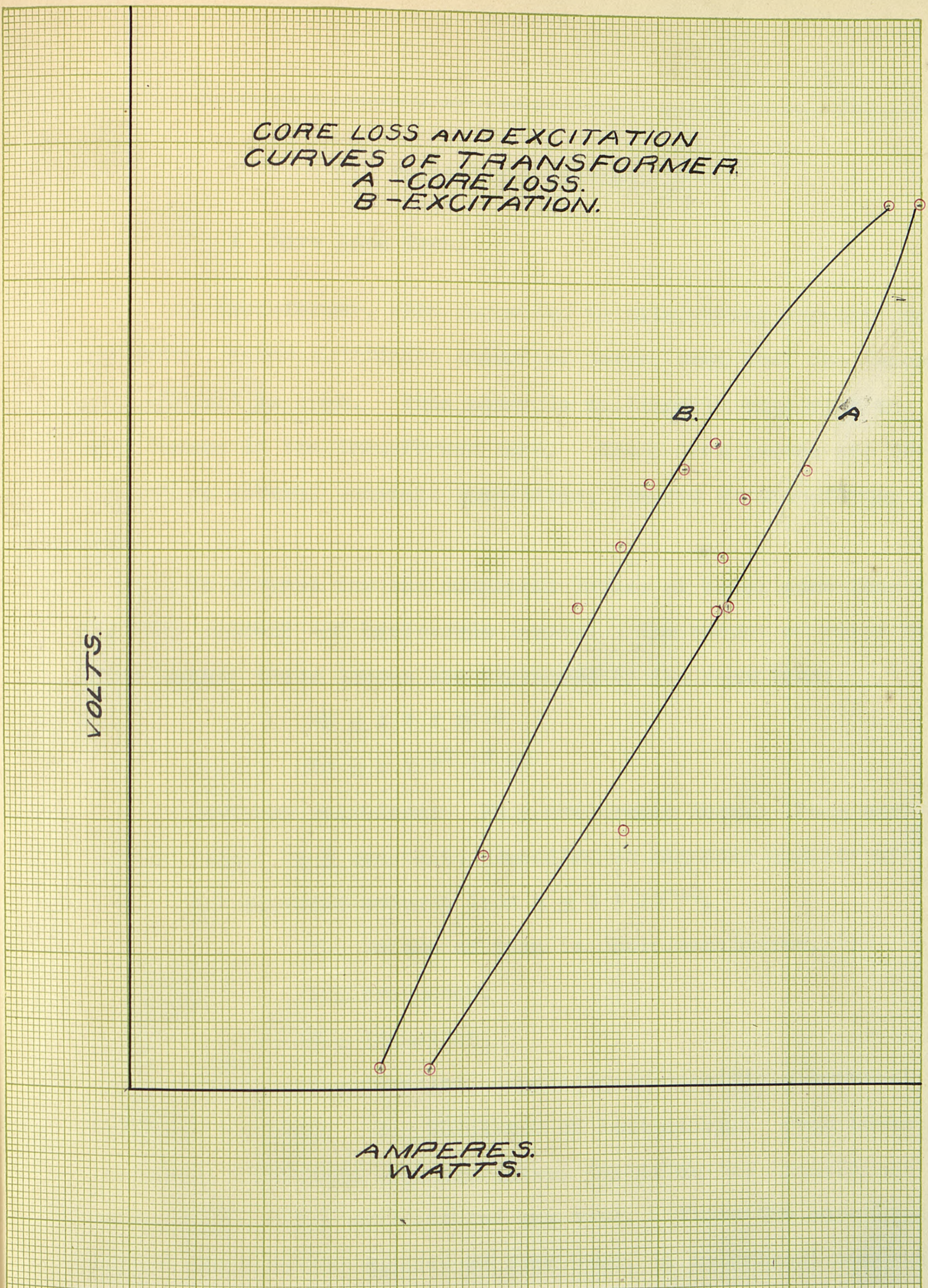
Hence, the total primary impressed E.M.F. by combination of $OE'r_0$, OEx_0, and OE' by means of parallelogram of E.M.F.$_s$ is, $E_0 = OE_0$, and the difference of phase between the primary impressed E.M.F. and the primary current is $B_0 = E_0 0\ F_0$.

In the secondary circuit:

Counter E.M.F. of resistance is $I_1\ r_1$, in opposition with I_1, and represented by the vector $OE'r_1$; Counter E.M.F. of reactance is $I_1 X_1$, 90° behind I_1, and represented by the vector $OE_1 x_1'$.

Induced E.M.F.'s, E_1' represented by the vector OE_1'. Hence the secondary terminal voltage, by combination of $OE\ r_1'$, $OE\ x_1'$, and OE_1' by means of the parallelogram of E.M.F.$_s$ is $E_1 = OE_1$, and the difference of phase between the secondary terminal voltage and secondary current is, $B' = E_1' 0.F_1$. As will be seen in the primary circuit the "components of impressed E.M.F. required to overcome the counter E.M.F.$_s$" were used for convenience, and in secondary circuit the "counter E.M.F$_s$" performing the differentiation, gives $E_1 = 2\pi f\ S\ N \sin 2\ f\ t \div 10^8$.

The effective value of this electromotive force is obtained by substituting for, sin $2\pi f$ t its square root of mean square value $\frac{1}{\sqrt{2}}$ giving for E the value 4.44 f S N $\div 10^8$ the fundamental transformer formula.



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TRANSFORMER TESTING.

I Core Loss Test.

A transformer, when connected to alternating current supply mains, takes a definite amount of power, even when the secondary circuit is open. This power is utilized in supplying the iron losses in the transformer core. These iron losses are dependent on several constant quantities, insured by transformer design.

In general the two component losses of total core loss are the eddy current and hysteresis losses. The amount of power needed to supply these losses are expressed by the equations:

$$Ph = A\ V\ f\ B^{1.6}$$

$$Pe = b\ V\ f^2\ 1^2\ B^2$$

In these relations: Ph = hysteresis loss. Pe = eddy current loss. a = constant, depending on magnetic quality of iron. For annealed wrought iron $a = 3 \times 10^{-10}$.

V = Volume of iron in Cubic centimeter.

f = Frequency.

B = Induction.

bb = Constant, depending on specific electrical resistance of iron. b = thickness of lamination. From these equations, it is seen that the losses depend on the transformer construction, being constant for any type. Since the core losses are dependent on the quality of iron used, it is evident that the constant power required for supplying these losses is subject to design.

The methods of obtaining core losses used was the one commonly employed in these tests. The voltmeter and pressure coils of the wattmeter were connected directly to the terminals of the transformer. The volts drop were read on the voltmeter, while the ammeter, in circuit, read the current. In this method the ammeter also reads, in addition to the magnetizing current, the current taken by the voltmeter and pressure coils of the wattmeter.

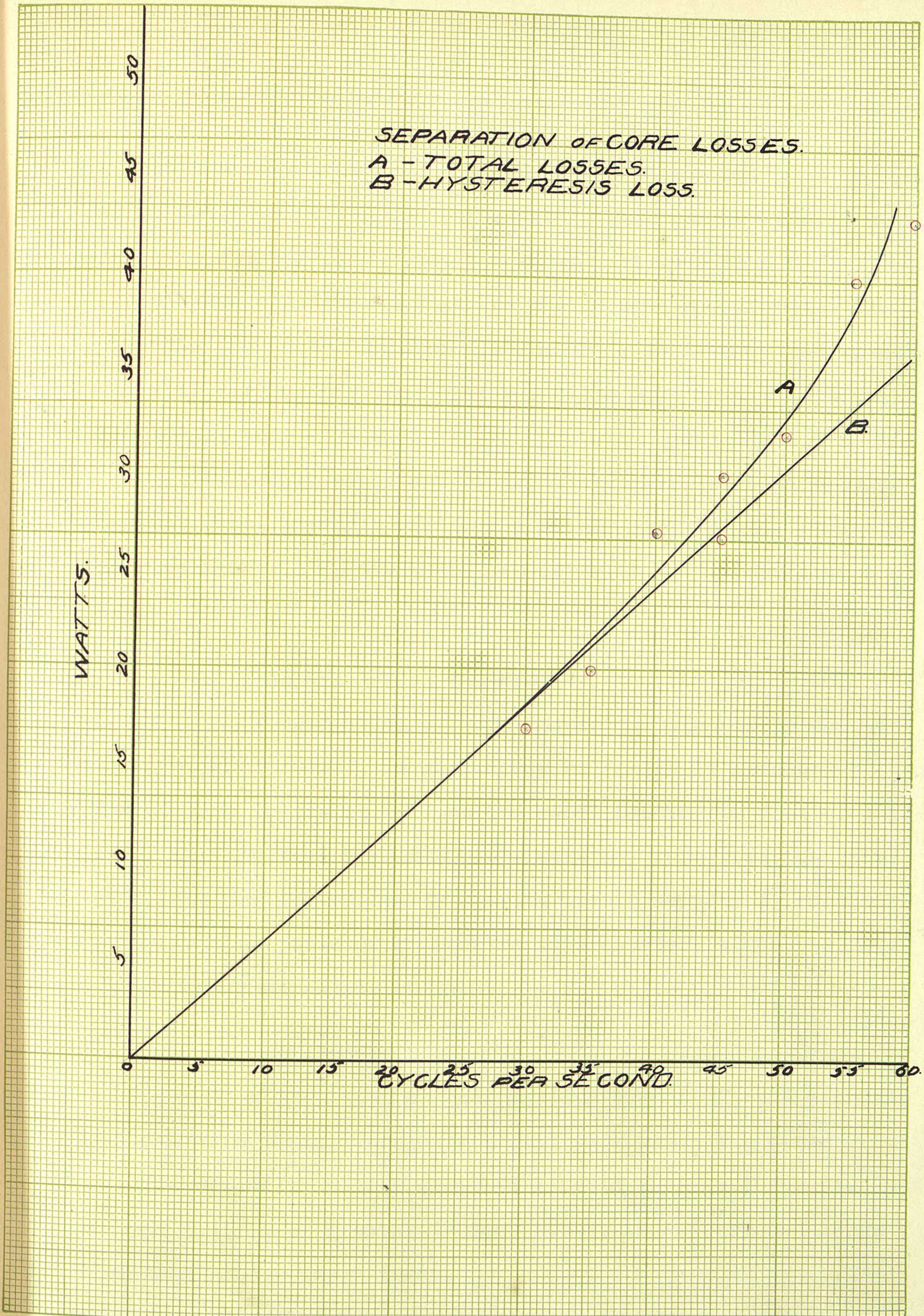
The frequency of supply volts was 60 cyles per second, the low tension side of the transformer being used for primary.

D A T A

Core Loss	Primary Amperes	Primary Volts	Terminal Volts
15 Watts	.485	71	109.5
25 "	.698	86.5	109.2
29.8 "	.89	94	109.8
30 "	.975	96.75	109
31 "	1.04	99.25	111
34 "	1.135	101.33	111
34 "	1.18	101.7	110.9
41 "	1.54	110.2	111

Discussion:

The volts of the core loss test, as shown by the data indicate that for small magnetizing currents, the core loss is relatively small, increasing with greater current input.



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The maximum core loss was about 41 watts, with about 1.54 amperes for magnetizing current. Core loss is dependent on supply wave of E.M.F. For a peaked wave, the losses are less than for a flat topped wave. Alternators giving a sine wave may increase the core loss from 5 to 10% over alternators giving a peaked wave. Similarly a sine wave will give a smaller core loss than a broad flat topped wave of E.M.F.

In certain specimens of iron, the core losses increase with use until they have reached a rather high value. This is known as aging. In the best iron cores this is reduced to a minimum.

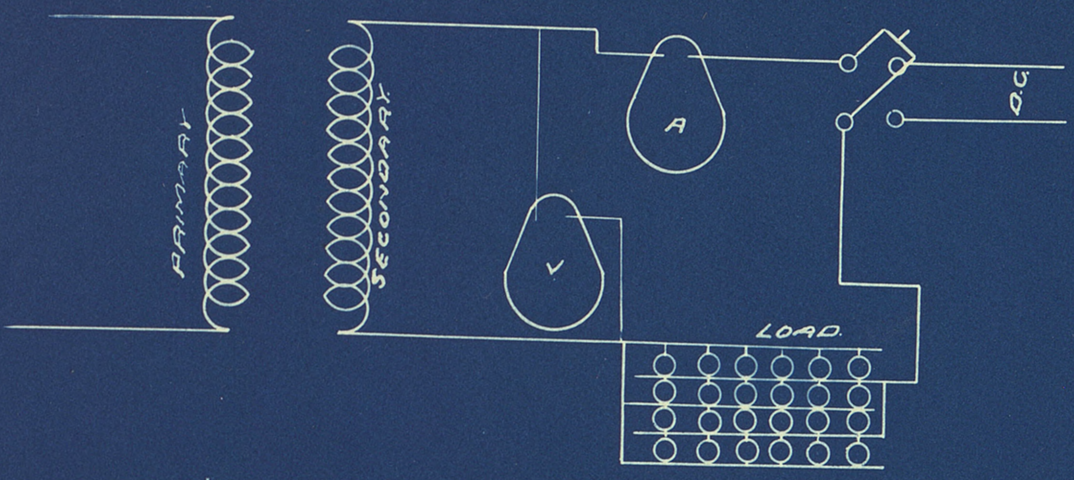
II. Separation of Core Losses:

A separation of core losses is valuable in the design of transformers. A good check on design is obtained by knowledge of such losses as well as the power needed for flux production. In this test the components were not separated, but the total loss was determined by keeping the induction, B, constant. To do this the ratio of $\frac{E}{\lambda}$ must be kept constant since the flux Φ is directly dependent on both.

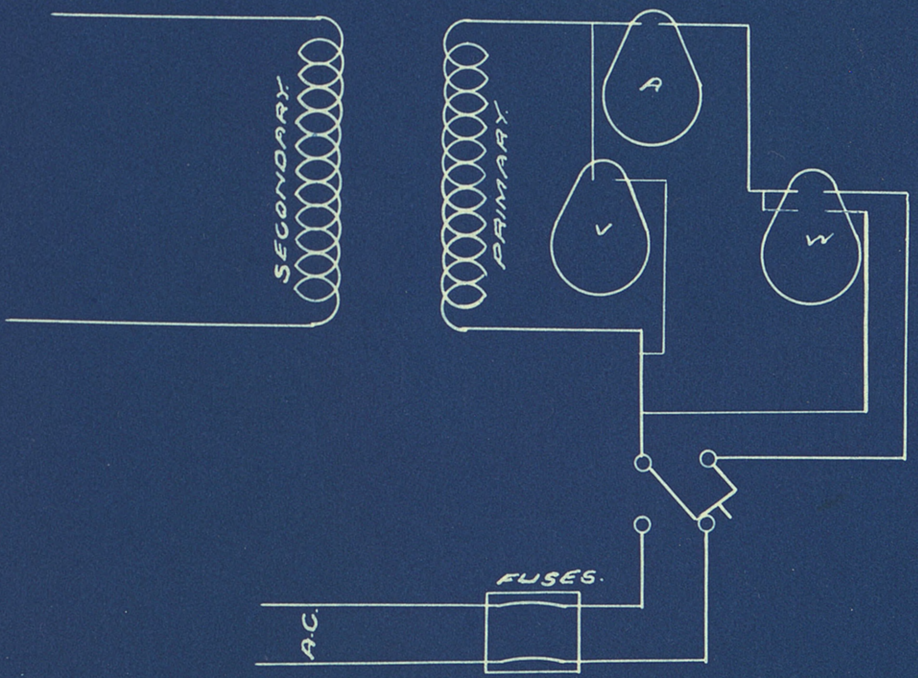
Proof:

Let Φ equal maximum core flux, and ϕ equals instantaneous flux. Assuming a flux sine wave; $\phi = \Phi \sin wt$.

Differentiating with respect to time; $\frac{d\phi}{dt} = w\Phi \cos wt$. But, $e' = N'\frac{d\phi}{dt}$, $e' =$ total induced E.M.F. in primary and large $N' =$ number of primary turns.



RESISTANCE MEASUREMENTS.



CORE LOSS SEPARATION.

$\therefore$ $e' = M' w \Phi \cos w t$. or $e' = N' w \Phi \cos wt$, also

$\Phi = \frac{e'}{N w} = \quad = \frac{\sqrt{2} E'}{N' 2\pi f}$. This shows that, $\frac{E'}{f}$, being constant, the flux ϕ will also be constant, which insures constant induction.

D A T A.

Watts	Volts	Amperes	r.p.m.	Cycles.
43	110	1.42	1200	60
40	100.8	1.45	1100	55
32	91.6	1.45	1000	50
30	82.5	1.44	900	45
27	76.3	1.56	800	40
20	64	1.3	700	35
17	55	1.43	600	30

III RESISTANCE MEASUREMENTS.

The resistance of thewindings of a transformer must be known before the efficiency and regulation can be calculated. The regulation being directly dependent upon the copper loss.

The resistance can be calculated for commercial purposes by the fall of potential method using direct current from storage batteries or other sources of supply.

The total copper loss may be calculated from the equation $W = R_1 I_1^2 + R_2 I_2^2$ where R_1 and R_2 are the resistances of the primary and secondary windings respectively, I_1 and I_2 being the sorresponding currents.

This method of calculating the resistance is subject to a few sources of error which are as follows:

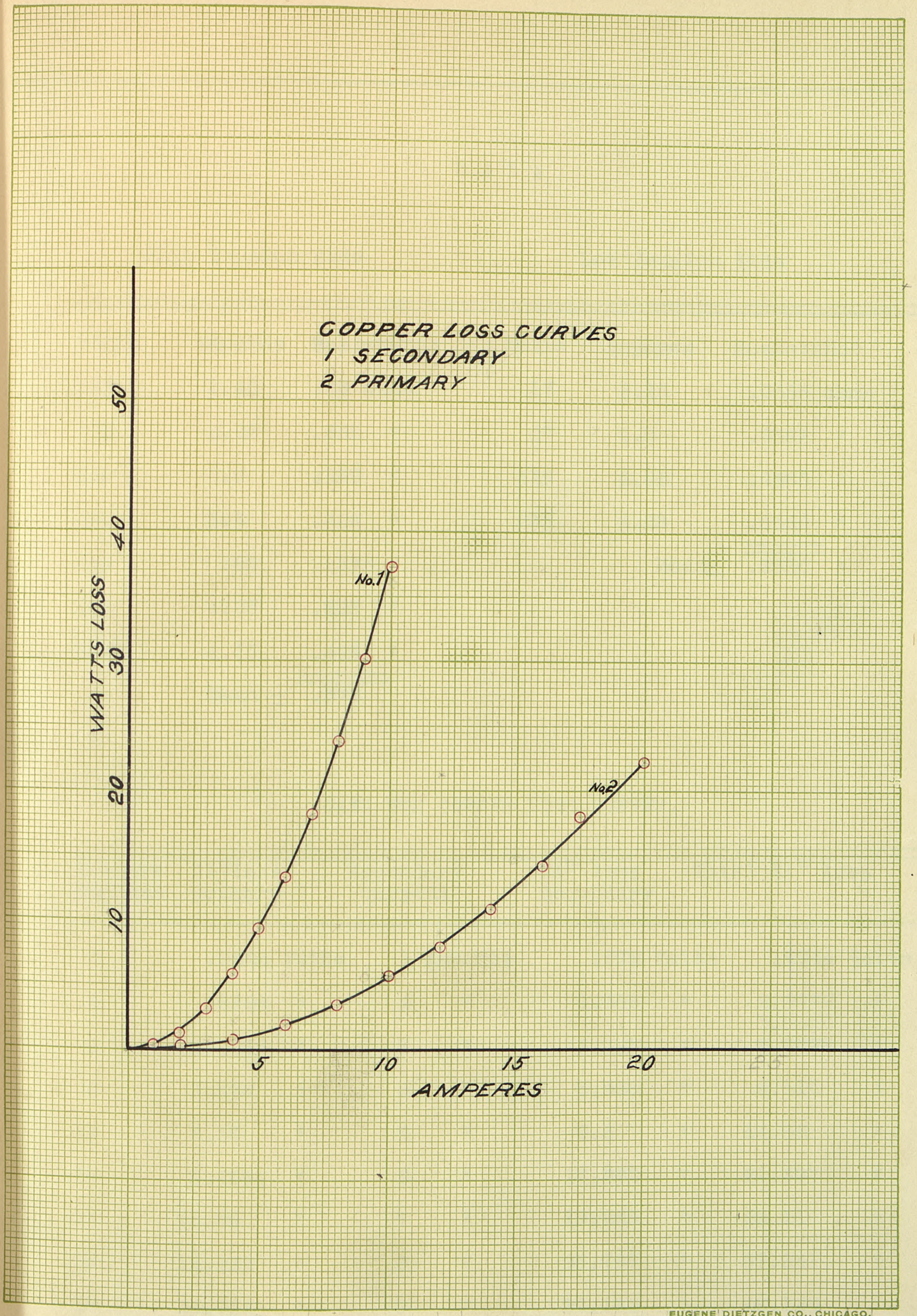
(a) When the ammeter is placed in the circuit and the voltmeter is connected directly across the winding. The ammeter reading will include the current in the voltmeter, and in order to prevent appreciable error, the voltmeter resistance should be many times greater than the resistance being measured. This may be illustrated by the following example:

If the resistance of the voltmeter is 1000 times greater than the resistance being measured, then the error is 1/10 of 1%, while if the voltmeter resistance was only 100 times greater, the mean error introduced would be 1%

(b) The resistance of copper increases very rapidly with increase of temperature, and hence the current used in measuring the resistance should be small as compared with the carrying capacity of the coil.

Care must, therefore, be taken not to use more than 25% of the normal working current, or a large error will be introduced.

The resistances measured may be reduced to a standard temperature, say 25° C. This may be done by means of the equation which is explained under the subject of heat test.



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D A T A

High Tension Side			Low Tension Side		
Volts	Amperes	Resistance	Volts	Amperes	Resistance
155	1.45	.38 ohms	17	3.15	.0555 ohms
75	2.02	.365 "	27	4.8	.0562 "
109	2.6	.419 "	115	2.05	.0560 "
151	3.7	.408 "	235	4.28	.0550 "
159	.85	.1875 "		Mean =	.0556 "
171	4.25	.423 "			
202	4.75	.425 "			
	Mean =	.372			

DATA FOR COPPER LOSS CURVES.

Primary Current	RI^2 loss primary	Secondary Current	RI^2 loss Secondary	Total RI^2 loss
2	.2224 Watts	1 Amperes	.372 Watts	.5944 Watts
4	.8896 "	2 "	1.488 "	2.3776 "
6	2.0016 "	3 "	3.348 "	5.3496 "
8	3.558 "	4 "	5.958 "	9.516 "
10	5.56 "	5 "	9.3 "	14.86 "
12	8.0064 "	6 "	13.392 "	21.397 "
14	10.89 "	7 "	18.228 "	29.11 "
16	14.233 "	8 "	23.708 "	37.941 "
18	18.014 "	9 "	30.132 "	48.146
20	22.24 "	10 "	37.2 "	59.44 "

Discussion:

The copper loss is as before stated, the loss due to the resistance of the primary and secondary windings. This loss is governed by the current density of the windings, and the distribution of the copper. The loss varies as the square of the load, i.e. at half load it is 1/4 and at quarter load it is 1/16 as great as at full load.

This is shown by the curves which are plotted with load as abscissas and watts loss as ordinates.

IV REGULATION TESTS.

The steady improvements which have been made in the construction of alternating current transformers of recent years, has enabled them to regulate much better, and, in a certain sense, regulation is of more importance in incandescent lighting than is efficiency. For, with poor regulation, the station manager can not give satisfaction to the consumer at any price.

The decrease in secondary voltage with increase of load on the transformer is due to the increased copper loss and magnetic leakage. On a non-inductive receiving circuit, the decrease of secondary voltage is due almost entirely to the copper losses. However, in the case of transformers on inductive receiving circuits the decrease in secondary volltage is due largely to magnetic leakage.

The leakage has two effects upon the transformer;

(a) It tends to decrease the secondary voltage.

(b) It tends to diminish the power factor.

This may be explained by means of the following discussion: Let us consider a transformer with a certain amount of leakage, working on a non-inductive load. If it were not for this leakage the voltage drop would only be due to the R I drop in the two windings. The voltage drop would therefore be in this case

$$d V_2 = C_2 r_2 + \frac{C_1 r_1}{r}$$

The drop in the primary $c_1 r_1$, is expressed in terms of the secondary drop by dividing by (k), the ratio of transformation, but since leakage is present, the drop will be greater.

Let N_1 = leakage field in primary.

N_2 = " " in secondary.

e_1 = reactance voltage produced by N_1.

e_2 = reactance voltage produced by N_2.

X_1 = reactance of primary.

X_2 = reactance of secondary.

Then $e_1 = 4.44 f S_1 N_1 \div 10^8 = C_1 X_1$

$e_2 = 4.44 f S_2 N_2 \div 10^8 = C_2 X_2$

From this a triangle can be constructed in which one side

$$A B = C_2 r_2 + \frac{(C_1 r_1)}{k}$$

and the other side

$$B C = C_2 X_2 + \frac{C_1 X_1}{k}$$

The hypothenuse, or resultant, gives the quantity upon which the voltage regulation depends. Its phase relation to secondary voltage depends upon the load, that is whether the current be lagging, leading or in phase. The secondary drop is a maximum for a given current when the secondary current lags behind the terminal pressure by an angle (90^o-B), where B is the angle between the side BC and the resultant. This resultant is proportional to the secondary current and always bears the same relation to it no matter what the load is. The leakage is the same for a given load whether it be non-inductive or inductive, and it reaches its maximum at full load. The leakage comes more in phase with the copper drop on inductive loads, and hence the secondary drop in voltage is greater than in the case of non-inductive loads.

The regulation of the transformer may be determined by direct measurements or by calculation. Both methods were used in this test.

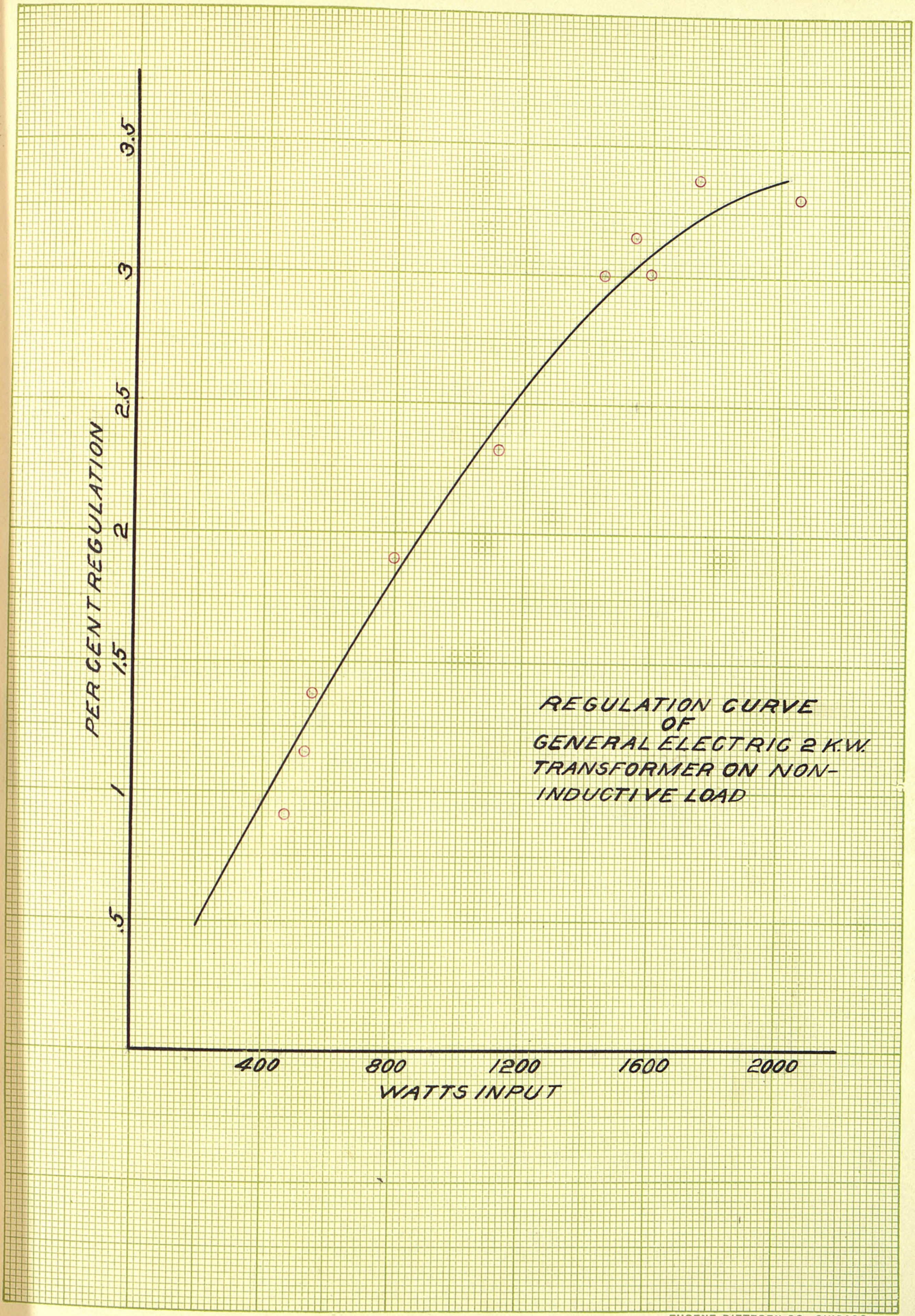
In the first method the transformer is excited at rated frequency and at such a primary voltage, that the rated secondary voltage is obtained at full load, using lamps as loads. The increase in secondary voltage from full load to no load is then observed, the primary voltage and frequency being kept constant throughout the test. There is a small error in this method because of the small difference in voltage, and the liability of error in measuring them.

The second method is much more reliable, several methods having been proposed for the calculation of the regulation. The following is the method which has been recommended.

Let IR = total resistance drop in the transformer expressed in per cent of the rated voltage.

IX = reactive drop similarly expressed.

P = proportion of energy current in load, or "Power Factor"


PER CENT REGULATION
.5
1
1.5
2
2.5
3
3.5
400
800
1200
1600
2000
WATTS INPUT
REGULATION CURVE
OF
GENERAL ELECTRIC 2 K.W.
TRANSFORMER ON NON-
INDUCTIVE LOAD

of load.

W = wattless factor of primary current with non-inductive load, W = magnetizing current expressed as a decimal fraction of full load current.

Secondary full load voltage = 100 per cent.

Secondary no load voltage = E

For non-inductive load:

$$E = \left((100 + PIR + WIX)^2 + (IX)^2 \right)^{\frac{1}{2}}$$

For inductive load:

$$E = \left((100 + PIR + WIX)^2 + (PIX - WIR)^2 \right)^{\frac{1}{2}}$$

The reactive drop expressed in per cent

$$= IX = \left((\%\ \text{impedence drop})^2 - (IR)^2 \right)^{\frac{1}{2}}$$

The magnetizing current =

$$\left((\text{exciting current})^2 - \left(\frac{\text{coreloss}}{\text{voltage}}\right)^2 \right)^{\frac{1}{2}}$$

D A T A

NON INDUCTIVE LOAD

Primary Current	Watts input	Load Secondary Voltage	No Load Secondary Voltage	% Regulation.
4.2	470	218	220	.917
4.7	530	217.5	220	1.15
5.05	550	217	220	1.38
7.25	810	215.8	220	1.9
9.06	1030	214.9	220	2.3
13.1	1450	213.5	220	3.04
14.1	1550	213	219	3.28
14.4	1600	213.5	220	3.04
15.5	1750	212.5	220	3.53
18.5	2065	211.75	220	3.43
Inductive Load				
29.5	800	213	221	3.53
31	211	211	220	4.26

Calculation for Non-Inductive Load Regulation.

Primary resistance R = .0556 ohms

Primary RI = .6565 volts = .597%

Secondary resistance R = .372 ohms.

Secondary RI = 2.197 volts = .999%

Total RI = 1.596.

Impedence drop = 2.502.

Reactive drop = 1.904%

Exciting current = 1.54. Hence magnetizing current = 1.502

Now as secondary load voltage = 100% and W = $\frac{1.502}{16}$ = .0939%

E = 101.71 or per cent regulation = 1.71%

Inductive Load:

Primary Current = 11.8 amperes.

Secondary Current = 5.9 amperes.

With power factor of 78.6%, the wattless factor of load is .6.

E = 102.3 volts or per cent regulation = 2.3%

DISCUSSION:

The regulation curve shows very nicely the decrease of regulation with load; which is in this case due to the large increase in the copper losses. These losses increase as the square of the load, the regulations being independent of the core or iron losses.

V. IMPEDENCE TEST.

As the impedence in the alternating current is equivalent to the resistance in a direct current circuit, the impedence of the transformer may be calculated from the equation $C = \frac{E}{X}$ or $X = \frac{E}{C}$ where E is the primary pressure required to drive a given current (C) through the short circuited secondary of the transformer.

The voltage thus required is known as the impedence voltage. The phase relation between the impedence volts and secondary induced volts determine the value of the latter. Hence the drop is a maximum when the secondary is short circuited, because the two voltages are in opposition to each other.

The impedence of the transformer is determined by short circuiting one of the windings, and taking measurements of volts, amperes and watts input on the other side. The impedence of the transformer may be considered as constant for all loads. The impedence calculated from the ammeter and voltmeter readings includes that of both the primary and secondary windings.

D A T A

Line Voltage	Watts	Reactance Voltage	Current	Impedence
110	19	2.05	9.87	.2075
110	20	1.575	9.87	.233
110	21	2.75	11.8	.1596
			Mean	,205

DISCUSSION:

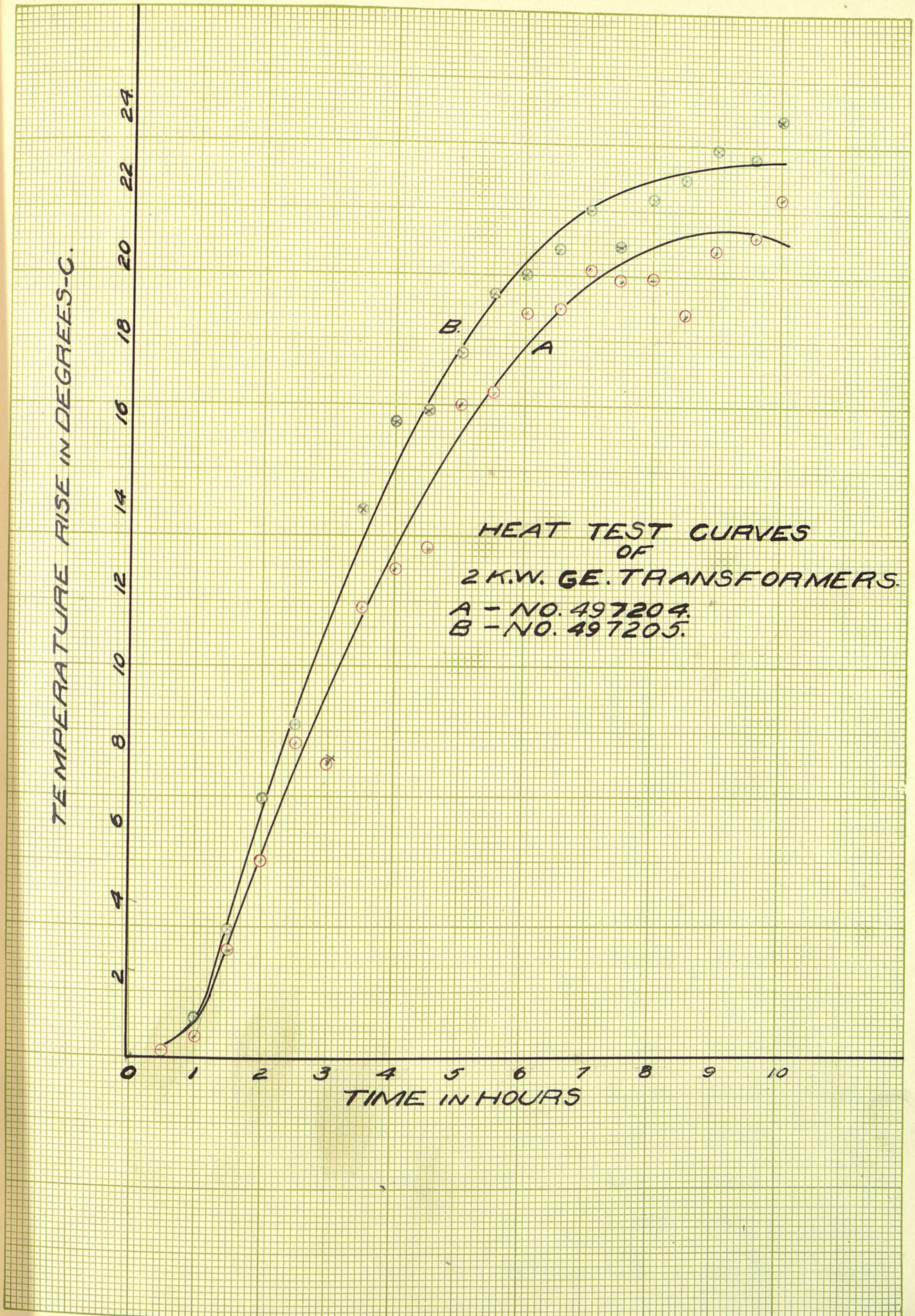
The wattmeter reading gives the I^2R loss in the primary and secondary windings of the transformer, in addition to a small core loss corresponding to the impedence voltage of the transformer, and a variable amount of eddy current loss. The core losses, however, are so small that they can be neglected.

Care should always be taken to keep the frequency constant, for the reactance will vary in nearly direct proportion to it.

VI HEAT TEST.

A very important test in determining the commercial operation of a transformer is the heat test. In this test the heating of the coils, core,and oil are measured. The standard time for a heat run is 10 hours at full load. In many cases it is advisable to overload the transformer about 25% for several hours when time is not available for the test.

In the method used, the primary was connected to the mains, the secondary being loaded with lamps. Frequent readings of temperature of all accessible points were measured by thermometers while the heating of the coils were determined by resistance measurements. Two transformers were used, having their primaries connected in parallel. The independent secondaries were loaded to full load, the temperatures of the various parts being measured by thermometers. A ten hour run was made, the increase of resistance being determined both before and after the test.


HEAT TEST CURVES
OF
2 K.W. GE. TRANSFORMERS.
A - NO. 497204.
B - NO. 497205.
A
B.
TEMPERATURE RISE IN DEGREES-C.
TIME IN HOURS
0
1
2
3
4
5
6
7
8
9
10
2
4
6
8
10
12
14
16
18
20
22
24

D A T A

Volts Primary	Amperes Prim.	Amperes Sec.	Watts Prim.	Watts Sec.	Temp.	Time
110	16	8	1.63	1.556	25	10.30
110	16	8	1.63	1.556	25	11
110	18	9.7	2.28	2.25	25.5	11.30
110	17	8.8	1.93	1.9	27.8	12
110	16	8.7	1.93	1.85	30	12.30
111	16.25	8.7	2.02	1.9	33	1
110	16	8.7	2	1.86	35.75	1.30
110.75	16.1	8.89	2	1.88	40.5	2
110.75	16.25	8.9	2.01	1.92	41.5	2.30
110.5	16.1	8.68	2.02	1.896	44	3
110.75	16.3	8.65	2.02	1.9	45.6	3.30
110	16	8,8	1.99	1.84	46	4
110.25	16	8.8	2	1.86	50	4.30
110.15	16	8.8	1.98	1.896	49.9	5
112	16	8.8	2.02	1.8	50.7	5.30
110.75	16	8.8	1.98	1.85	50.5	6
111.5	16	8.8	1.95	1.834	51.1	6.30
112	15.8	8.8	2.02	1.8	50.3	7
113	16	8.8	2	1.8	52.8	7.30
113.5	15.6	8	2	1.862	53	8
	16	8.8	2.01	1.9	53.25	8.30

#497205.

Amperes Prim.	Amperes Sec.	Volts Sec.	Temperature	Room Temp.	Time
16	8	212	25	25	10.30
16	8	212	25		11
18	9.25	230	26		11.30
16	8.7	214	28.25		12
17.5	8.75	212.5	30.25		12.30
18	8.9	215	33.5		1
18	8.85	214	36	28	1.30
18	8.8	217.5	43	29	2
18	8.67	213	45.3		2.30
17.75	8.85	213	45.5		3
16.7	8.4	214	47		3.30
16.7	8.3	213	48.5		4
18	9	216	50.6	30.75	4.30
18.1	9	216	51.5		5
18	9	217	52.5		5.30
18	8.92	214	52		6
18	8.98	216	53.3	31.5	6.30
18.1	9.05	217	54.5	32	7
18	9	218	55.5		7.30
18	9.1	220	55.2		8
18.3	9.15	220	56	31.3	8.30

DISCUSSION:

The increase of resistance of the coils was measured after the test, the ammeter voltmeter method being used.

#497204.

High Tension			Low Tension.		
Volts	Amperes	Resistance	Volts	Amperes	Resistance.
.6	1.14	.527	.32	4.03	.0795
1.72	3.4	.506	.45	5.63	.0798
2.65	5.43	.488	.58	7.15	.0812
Mean Res.		.507 Ohms	.78	9.8	.0796m
			Mean Res.		.08003 ohms.

#497205

1.3	2.47	.526	.3	3.58	.0848
2.6	5.02	.517	.5	6.25	.081
2,77	9.18		.7	8.42	.0832
			.86	10.46	.0823
Mean Res.		.522			.0828

The heat rise of the coils is, as a rule, determined at the conclusion of the heat run. The increase of resistance of the coils is used in this test. A formula often used is:

$$Th = \frac{Rh\,(1 + .004\,T_e\,) - Rc}{.004\,Rc}$$

TH = temperature, hot

Tc = " , Cold.

Rh = Resistance, hot.

Rc = " . cold.

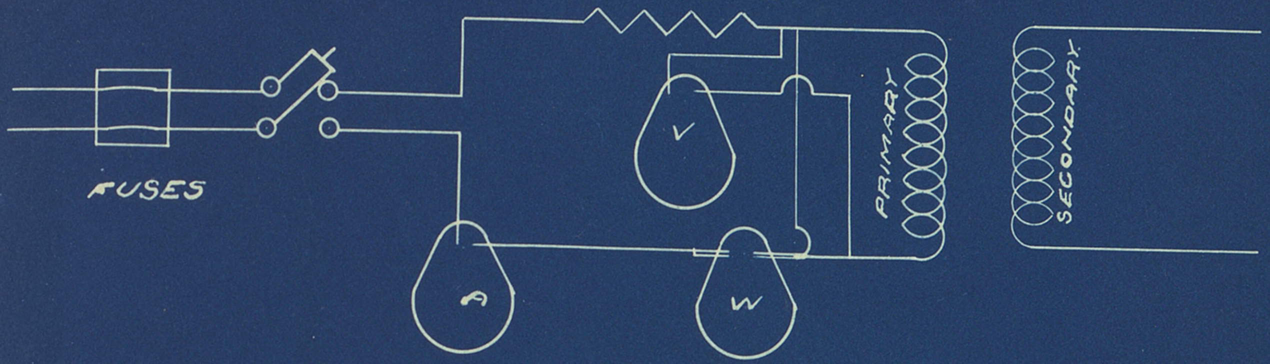
#497204.

Resistance 110 Volts side	Resistance 220 Volts	Temperature Cold	Temperature Hot Calculated.
Hot .08003	.507	25° C	Sec 220 96.7° C.
Cold.0556	.372	25° C	Prim 110 64.3° C.

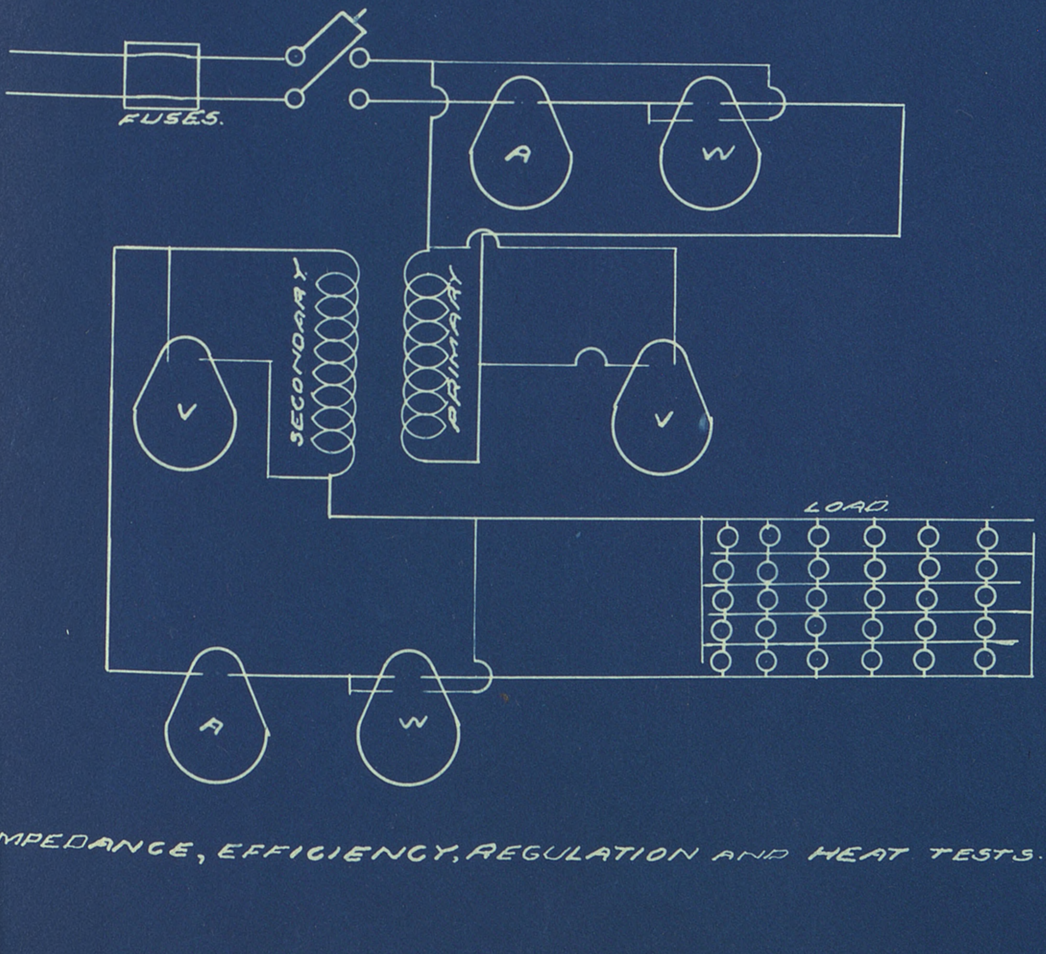
#497205.

Values of resistance cold, not know, (test run for comparison.)

The high values of final coil temperatures are possible for a run at full load for the time of test. The small capacity of the transformer insures a very high final temperature of the coils, inasmuch as the coils are compactly wound, and there is little radiation area. A low coefficient of radiation of oil would tend to produce such high results.



CORE LOSS AND IMPEDANCE TESTS.



IMPEDANCE, EFFICIENCY, REGULATION AND HEAT TESTS.

VII

EFFICIENCY OF TRANSFORMER.

Transformer efficiency is defined as the ratio of output to input of power expressed in per cent. Since the only losses are the core and copper losses, it is evident that by good design, a very high efficiency may be obtained.

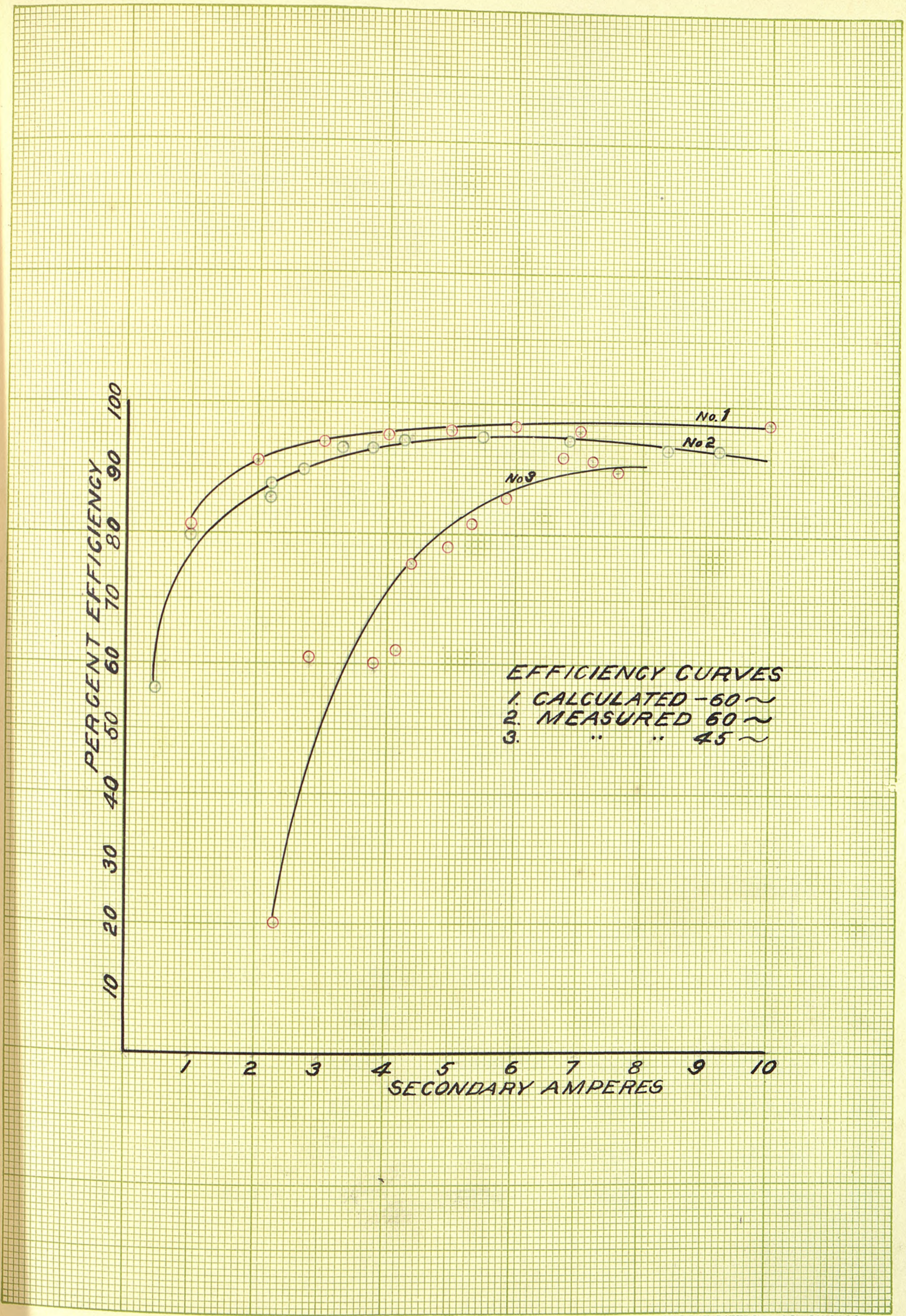
There are two general methods for determining the efficiency of the transformer. A method often used for large transformers is the "stray power" method. In this method the output is calculated from the assumed values of input by subtracting from the input the core and copper losses. The ratio of output to input, is, of course, the computed efficiency.

The efficiency's of small and medium sized transformers are determined from direct measurement. With care, accurate working conditions can be deduced from such results. In these tests both methods were used.

The all-day efficiency of the transformer was obtained from the data of the heat test. In the computations, a ten hour day load is assumed. A no load period of fourteen hours was thus taken. The fundamental formulas used in the efficiency computations are:

(1) "Stray power" method.

$$\text{Efficiency} = \frac{\text{Watts input} - I^2 R - \text{Core loss}}{\text{Watts input.}}$$



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(2) Direct measurements.

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input.}}$$

(3) All day efficiency $= \frac{\text{Output (24) hours)}}{\text{Input (24 hours)}}$

D A T A.

Measured Results.

Primary Watts	Volts Primary	Current Primary	Watts Secondary	Current Secondary	Volts Secondary	%Effic.
50	110	0	0	0	220	0
316	110	1.3	200	.5	220.75	56.2
275	110	2.3	220	1	220.75	80
575	110	4.83	498	2.2	219.5	85.7
525	1110	4.76	460	2.2	219.5	87.6
600	110	5.7	540	2.7	219	89.8
750	110	6.83	700	3.3	219.25	93.5
855	110	7.71	800	3.75	218.75	93.2
855	110	7.82	810	3.75	218.75	94.7
977	110	8.75	920	4.25	219	94.2
989	110	8.96	940	4.35	219	95
1575	110	13.9	1490	6.85	218.5	94.6
1578	110	13.99	1480	6.85	217.5	94
1960	110	17.2	1920	8.4	217.25	93
2100	110	18.2	1953	9.2	217.25	93

CALCULATED RESULTS:

60 cycles and 45 cycles were used in these tests.

60 cycles			45 cycles.	
Amperes (220)	Efficiency	Volts (Primary)	Amperes (220)	Efficiency
1	81	110	2.3	20
2	91	110	2.8	61
3	94	110	3.8	60
4	95	110	4.15	62
5	96	110	4.35	75.5
6	96.5	110	4.95	78
7	96	110	5.3	81.5
10	97.25	110	5.85	85.5
			8.75	92
			7.2	95.5
			7.6	89.8

In the all day efficiency test the sum of all the input of power was taken as was the total output.

OUTPUT

		K.W.Hours.
10 hours at full load	=	39.504
14 hours at no load	=	0
Total 24 hours	=	39.504

INPUT

10 hours at full load	=	42.07
14 hours at no load	=	.543
Total 24 hours	=	42.613

$$\text{All day efficiency} = \frac{39.504}{42.613} = 92.7\%$$

DISCUSSION:

In many cases on non-inductive loads the ammeter voltmeter products are taken as the output. The small inductance of the secondary coils is neglected, as the power factor of the circuit does not, in any case, differ much from unity. In all efficiency tests non-inductive loads are used, in order that no wattless current may enter in to increase the copper loss of the transformer.

Small core loss at all loads would give a good efficiency at light load, while for transformers operated at full load, large copper losses should be avoided. In general, a transformer can readily be designed for almost any load with good efficiency, if the conditions of operation are known.

GENERAL DISCUSSION.

In the transformer tested, a simple form of internal construction is used. The transformer is one of the core type, the secondary being arranged for parallel connection if so desired.

The normal rating of this transformer is 2 K.W. at 125 volts. This demands a primary current of 16 amperes and a secondary current of 8 amperes. If the transformer is to be used on 110 volt mains, as it was operated in the test, a large current would be necessary in both circuits if full load is to be obtained.

In American Companies few polyphase transformers are built. American pactice is to use large well ventilated and strongly constructed transformers, so arranged that the primaries may be either connected in parallel or series.

Regulation is one of the difficult points to provide for in transformer design. In large transformers where fineness of design is possible, the good grades of iron used, largely cut down the core loss. Where the transformers are to be used in power circuits, precautions should be taken to guard against magnetic leakage, as this is one of the factors influencing regulation.

The temperature of the coils and accessories should be kept as low as possible. A Large radiating surface is necessary to insure this result.

The resistance of the coils should be low if it is desired to cut down the copper losses under load conditions. Good regulation is also maintained on non-inductive loads when the resistance of the various windings are kept as low as is economical.

In practice special attention is paid to the insulation of the transformer coil; a value of two meg-ohms is given as a low resistance of insulation. The coils should be able to stand at least twice their normal voltage without a break down of insulation.

The transformer principle is applied in many cases in practical operation of alternating current apparatus.

There is no doubt, that owing to the data obtainable for good design, the high efficiency and good regulation possible, the transformer has done more than any other piece of apparatus for the very successful replacement of direct current by alternating current in power work.