TEST of G. E. TYPE H, TRANSFORMER.

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TEST of G. E. TYPE H, TRANSFORMER.

Fundamental principles.

Alternating current phenomena are at the present time approaching a stage of development which, when reaced, may be considered the master means for the control of power and illumination, Since a great part of the water power in the United States is being utilized by the engineer and converted into electrical energy and transmitted at high voltages to distant cities. Herein lies the use of the alternating current transformer.

A static transformer is a continuous laminated iron core interlinked with two electrical circuits, one of which receives electrical energy and the other delivers electrical energy. Fig. 2, Plate H. represents a simple transformer.

The coil which receives the electrical energy or that one over which the E.M.F. is first impressed is called the primary, and that coil which delivers electrical energy is called the secondary. Fig.'s 3 and 4, Plate H. represent diagramatically the core and shell types respectively. If the electric circuits surround the magnetic curcuit as in (3) the transformer is said to be of the core type. If the reverse is true as in (4) it is of the shell type. The ratio of transformation is designated by the ratio of the number of turns in the secondary winding to the number in the primary winding. If this ratio is greater than unity the transformer steps up the voltage, and if less than unity steps down the voltage. The one extensive use of the transformer lies in the fact that electrical energy may be taken

FIG. 1.

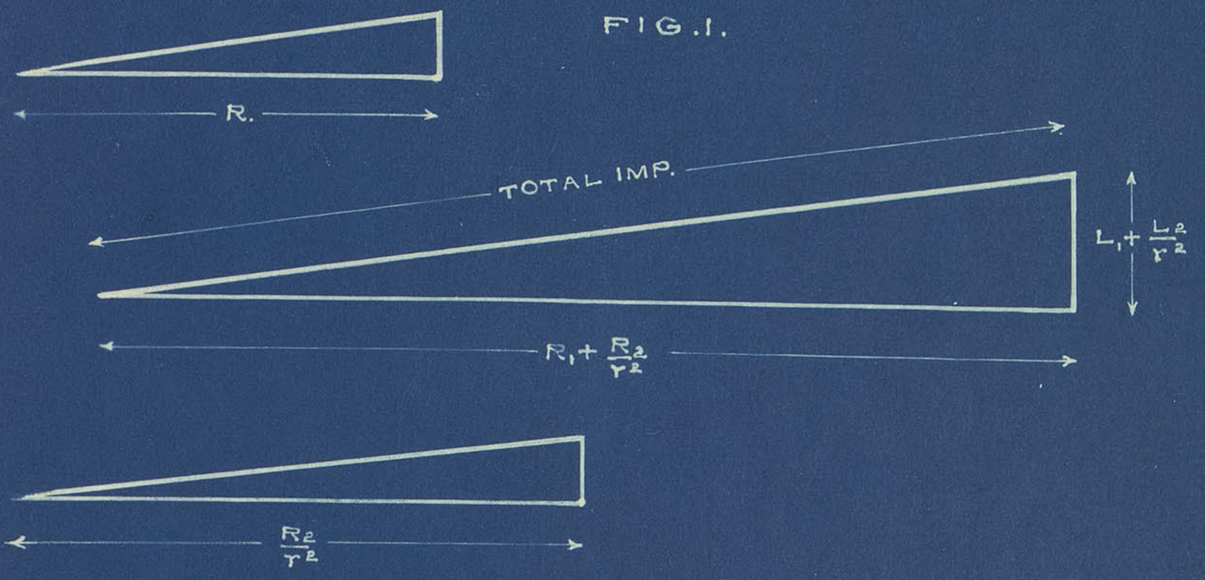


FIG. 2.

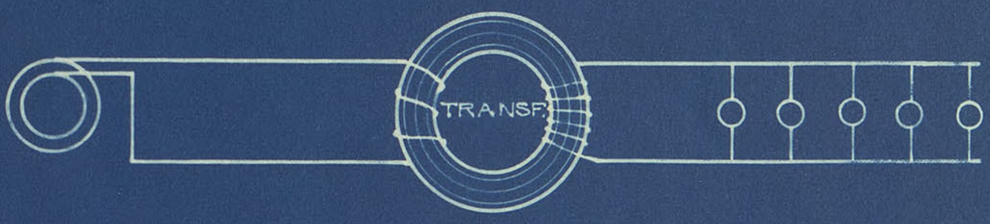


FIG. 3.

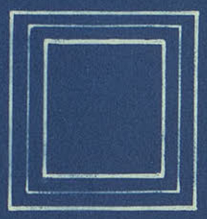
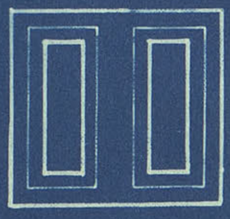


FIG. 4.



LWF.

into the primary winding and delivered from the secondary at a different pressure.

A transformer is designed for great reactance and small resistance in the windings. The result is that when a sinusoidal E.M.F. is impressed over the primary winding with open secondary, the current which flows is small and lags practically 90° behind the impressed E.M.F. When such is the case a flux is set up in the core which is in phase with the exciting current, for the reason that the induced E.M.F. is greatest when the time rate of change is greatest, and the flux changes fastest at the zero value of E.M.F.

The losses in a transformer are as follows:

Eddy Current.

Hysteresis.

Copper.

Eddy currents are caused by differences of flux distribution in iron. As a result electric currents are established which in solid core give rise to excessive heating and tend to demagnitize the the core.

Pe equals V $f^2 1^2 Bm^2$

k equals about 1.6 X 10^{-11}

V equals Volume of iron (c.g.s.)

f equals frequency.

1 equals thickness of laminae.

Bm equals maximum induction.

Laminations offer an oxide resistance for the eddy currents induced and decrease this loss very much.

The drop of E.M.F. due to hysteresis is composed of two components, the energy and wattless components. These are at right angles to each other. The former is in phase with the primary current and the latter in phase with the counter E.M.F.

Hystersis loss equals 10^{-7}V F U $Bm^{1.6}$.

V equals volume of iron (c.g.s.)

F equals frequency.

U equals const. equals (.002 to .003)

Bm equals max. flux.

In every transformer when loaded there is drop of voltage due to ohmic resistance and magnetic leakage in both the primary and secondary winding. When leakage occurs it is equivalent to cutting out a certain number of coils in the transformer and putting the same in circuit to cause inductance. The ohmic resistance and inductance are combined vectorily to get the equivalent drop both in magnitude and direction. See Fig. 1, Plate H.

Copper drop equals 1. R_1. plus $\frac{1.R_2}{r}$

1. equals current of primary.

R_1 resistance of primary.

R_2 equals resistance of secondary.

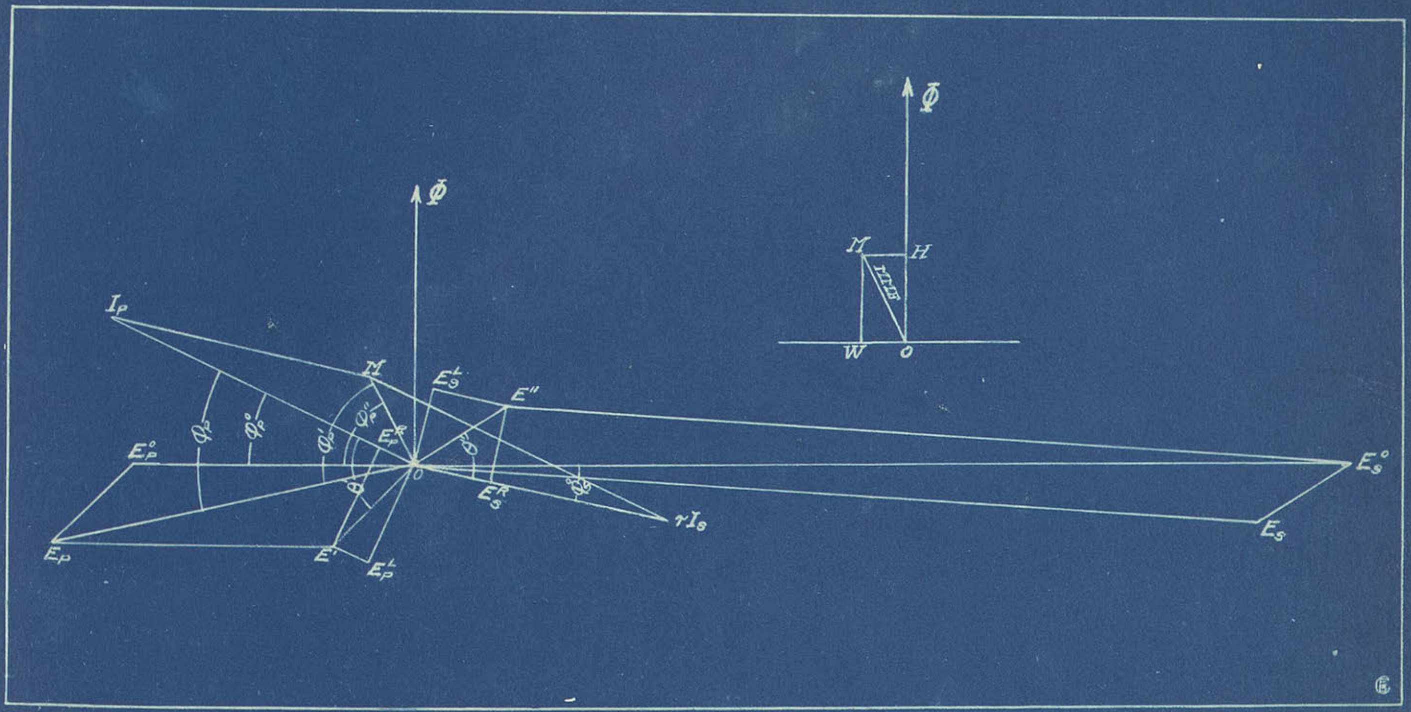
r represents the theoretical ratio of the number of turns in the secondary to the number of turns in the primary. This is modified by the resistance and inductance of each winding. Practically, the current in the primary is not 180° from that in the secondary on account of hysteretic lag. (See Steinmetz Diagram).

Leakage flux is considered that part of the flux which links the primary coil and not only is useless, but sets up an E.M.F. opposing that which is impressed. In the secondary winding there is also a similar leakage which is discussed more fully under transformer regulation.

Steinmetz Diagram.

The diagram invented by Steinmetz is a device by means of which the action of a transformer can be found for any load. From this diagram the losses which take place can be readily obtained so that the power necessary in the primary coils to deliver a certain power in the secondary can be readily determined. It is necessary in order to use this diagram to know the value of several constants of the transformer These constants, as will be explained, can be calculated by the designer or can be obtained by making a series of tests on the transformer in question.

The following diagram will serve to explain the method of procedure:



The line 0 Φ is drawn from any point o to represent the direction in which the flux acts which is useful and links both the primary and secondary coils. The value of Φ is not necessary in the design of the transformer. The primary E.M.F. which is operative in producing useful flux is at right angles and is represented by $E^{\circ}{}_{p}$. In phase with this is the ampere turns required in the no load exciting current to neutralize the effect of eddy currents and to effect the hysteretic change in cycles. The value of the current required to neutralize the eddy currents may be calculated by the designer by the use of the emperical formulae -

$$I_e \text{ equals } \frac{1.6\ V\ F^2\ U^2\ B^2m}{10''\ E_p}$$

And for hysteresis- I_h equals $\frac{V\ f\ .003\ B^{1.6}m}{10^7\ E_p}$ where

V equals Volume of iron in Cm.

F equals ∼.

U equals thickness of one lamination in Cm.

$$B\ m \text{ equals } \frac{\Phi m}{A} \text{ equals } \frac{10^8 \sqrt{2}E_p}{N_p\ W\ A}$$

E_p equals primary voltage.

N_p equals turns of primary coils.

W equals $2\pi f$.

A equals area of cross section of core in square C.m.

At right angles to this and in phase with the flux is the portion of the no load exciting current that is returned to the circuit called the magnitizing current. Its value may be calculated from the formulae -

$$I\ mag. \text{ equals } \frac{10\ l\ P\ \Phi m}{4\ \ 2\ \ N_p\ A} \quad \text{Where}$$

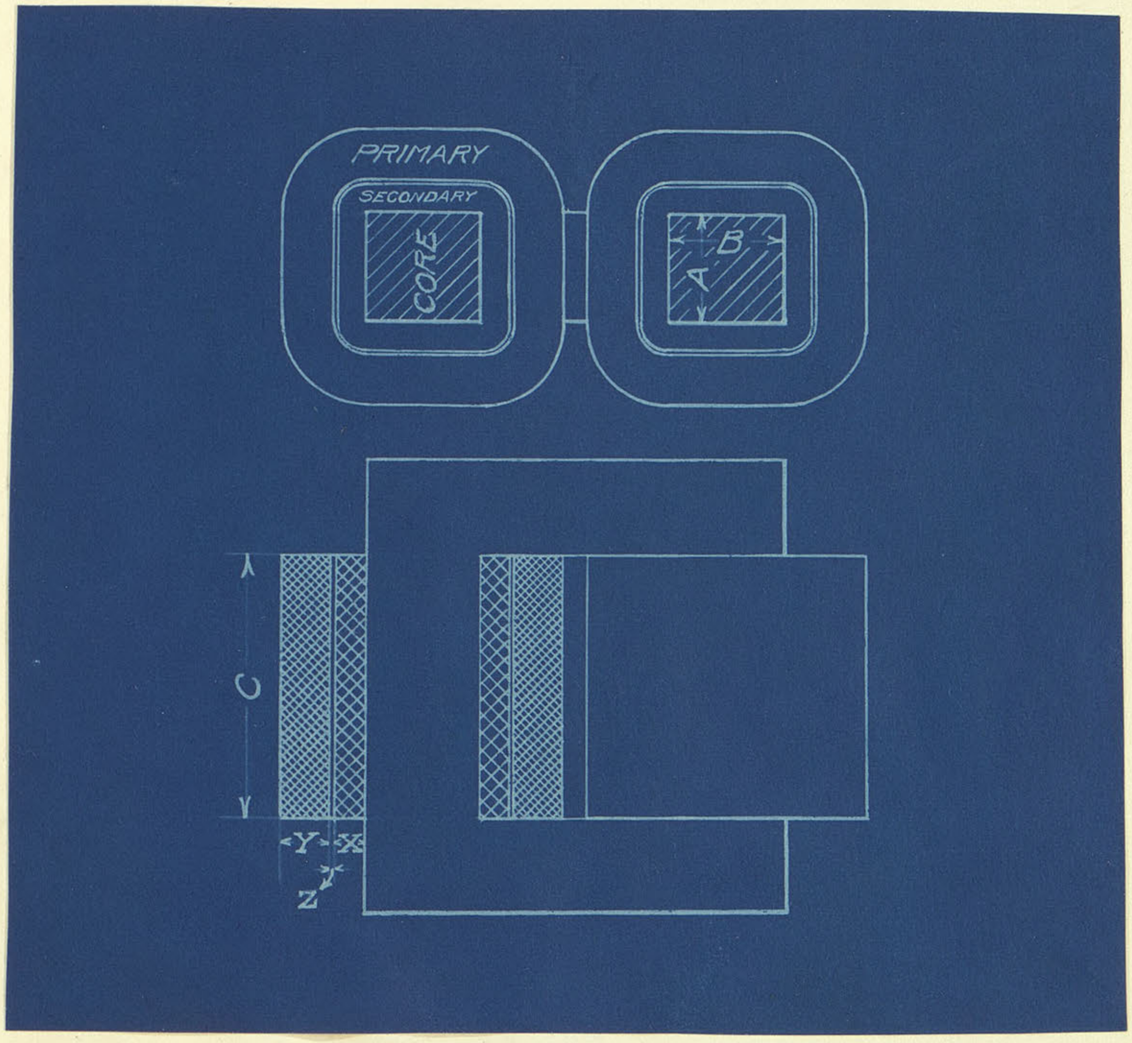
l is the length of the path in cm and P equals 1/y where y is the fermeability of the iron, so that we may combine the two components and obtain what will be the no load exciting current with its angular relation to the flux. In the diagram this is used in relation to the primary and secondary currents in ampere terms.

The total E.M.F. impressed over the primary is not operative in producing useful flux. There is a drop in voltage due to the resistance of the coils., and at right angles to it leading, is another drop due to the inductance of the leakage flux. The secondary voltage is also cut down for the same reasons. To find the inductance due to leakage flux the following formulae has bee deduced:

$$L_s = \frac{8}{109} \pi \frac{N_p^2 Y (A + 2X + 2Z) + (B + 2X + 2Z) + 3Y}{3(C + \pi Y)}$$

$$L_s = \frac{16}{10^9} \pi \frac{N^2 X (A + B + 3X)}{3(C + \frac{\pi}{2} X)}$$

Where the dimensions of the transformer are represented as in the following scheme:



This shows that the inductance due to leakage flux is independent of the current and remains the same for all loads. The resistance of the coils can be found by direct calculation from tables in handbooks. For sake of illustration let us assume now a current in the secondary of I_s when the angle of lag equals 0°_{s} between the internal volts and the current. The drop in voltage due to the resistance of the secondary is in phase with this and that due to inductance at right angles and leading. These can be laid off on a larger scale, if the work is to be done graphically, and the resultant obtained more accurately to be applied to the diagram at the same scale as will be used for volts. Let $0\ E^{r}_{s}$ be the volts lost in resistance and $0\ R^{L}_{s}$ that due to inductance, then $0\ E''$ the resultant. As we do not as yet know the internal volts in the secondary we cannot as yet obtain the value of the external volts. We now complete the parallelogram of the force lines 0 M and $0\ I_s\ T$, $0\ I_s T$ being the value in ampere terms of the secondary, considering but one turn for the primary turns, giving us the force line $0\ I_p$ which is the ampere turns in the primary. As we have now obtained the current and its phase relation in the primary we can construct the impedance drop as in the secondary and knowing the impressed E.M.F. of the primary obtain the operative E.M.F. $0\ E^{o}_{p}$. Having obtained this we multiply it by T and construct it on the opposite side as $0\ E^{o}_{s}$. The direction and value of the useful E.M.F. at the secondary terminals can now be obtained it being $0\ E^{o}_{s}$. Knowing the value of the voltage and current in the secondary with the angle of lag and the same for the primary we can at once calculate the efficincy.

If we wish to obtain the constants as before mentioned, in any transformer so that a diagram can be constructed it can be done in the following manner:

On the primary side place in the circuit the instruments as shown in the following scheme FIG. 1 A and take the value of the no load reading on each instrument.

The cosine of the angle θ'_p as shown in the diagram is equal to the no load watts divided by the no load volt amperes. In a five K.W. transformer this angle can be considered the same as $0''_p$ for the reason that the voltage drop due to impedence is very small due to a small current and will not cause a perceptible difference in the two angles.

As the drop is very small due to the impedance, at no load we can assume the impressed volts $0\ E_p = 0\ W^o_p$. To find now the value of T we divide the volt meter reading in the secondary by that of the primary. It is necessary to use a very high resistance volt meter in the secondary as a very small current will cause a much greater current to flow in the primary. The impedances can be found by the methods discussed and the resistance by direct current methods so that we are able now to work any problem which may be assumed.

To illustrate the method as described the following diagram has been constructed, the constants obtained being given in the table accompanying.

By means of this diagram we could calculate the efficiency of the transformer for all loads and obtain an efficiency curve. As this method would be tedious some other more simple method must be resorted to. There are three different methods used in commercial practice which are called by the following names to designate each:

1. The single conversion.
2. The double conversion.
3. The double conversion with a calibrated transformer.

The first method consists in placing the transformer with the primary coils over the proper primary voltage which is kept constant and loading up the secondary with the desired power factor. (In the specifications given in various books on testing a non-inductive load is used except when otherwise called for). The scheme for this test is as shown in Fig. 2, A.

The efficiency for any load on the secondary is equal to

$$\frac{\text{Watt "}}{\text{Watt "}}$$

It was impossible on account of not having the proper instruments to obtain good results by this method.

The method number 2. consists in placing two similar transformers together, that is, connecting the secondary leads of the first to that of the second and thus step the voltage back. The connections for this method are shown in Fig. 3, A.

In this method the losses in each transformer are considered the same, the efficiency of one being equal to $\frac{\text{Watt "}}{\text{Watt "}}$.

This was the method used in the test for the efficiency on the transformer in question. In one test the load was a non-inductive load of lamps and in the other an inductive load of varying power factor. Owing to some errors in the readings of the ammeters and voltmeters the power factor could not be plotted with the efficiency for the entire length of the curve. The load consisted of an induction motor belted to a direct current dynamon on a constant load of incandescent lamps, in parallel with a bank of incandescent lamps. From the nature of the load and the power factor curve we know that the power factor was low on starting and high as the load approached full load. It will be noticed from the two curves that the one taken with the inductive load falls below that taken with the non-inductive load. This should be the case for the reason that the voltage in the primary which is operative is cut down a great deal more than if there was no wattless current flowing, due to the impedance drop. The drop in the primary volts is multiplied T times in the secondary so that any current in the secondary lagging we will not have the same relation of the external volts for a large angle of lag as for a small angle, for it will be less. This drop in E.M.F., however, is not diredtly proportional to the angle of lag. To prove this, that there is a drop in volts and that it is not in a direct ratio, it will be necessary to refer to the previous diagram. For the sake of convenience let us consider the drop in relation to the ideal voltage in the secondary, namely $T\,OE_p$

Let E_d^S the difference between the actual volts and the ideal volts $T\,\overline{OE}_p$.

$$E_d^s = T\,OE_p - OE_s \quad (I)$$

$$OE_s = \left[OE''^2 + OE_s^{o2} - 2\,OE''\,OE_s^o \operatorname{Cos}(\theta'' - \varphi_8^o)\right]^{\frac{1}{2}}$$

$$OE_s^o = T\,OE_p^o$$

$$OE_p^o = \left[\overline{OE}_p^2 + OE'^2 - 2\,\overline{OE}_p\,OE' \operatorname{Cos}(\theta' - \varphi_p)\right]^{\frac{1}{2}}$$

Sub values in (1)

$$(2)\quad E_d^s = T\,OE_p -$$

$$\left[OE''^2 + T^2(OE_p^2 + OE'^2 - 2\,\overline{OE}_p\,\overline{OE}' \overset{\operatorname{Cos}(\theta'-\varphi_p)-2\,OE''T}{\wedge} \operatorname{Cos}(\theta''-\varphi_S^o)\left[\overline{OE}_p^2 + \overline{OE}^2 - 2\,\overline{OE}_p\overline{OE}'\operatorname{Cos}(\theta-\varphi_s)\right]^{\frac{1}{2}}\right]^{\frac{1}{2}}$$

The variables in this equation considering the secondary current constant and the angle of lag as the variable are, φ_S^o φp E_d^s and OE'. OE' being increased as the amperes in the primary are increased as will be explained later.

From the diagram it can be seen that as the angle φ_S^o is increased and as these angles are increased the value of Cos ($\theta'-\varphi p$) and

Cos $(\theta'' - Q^o_s)$ increase and approach one. (2) When the value of these variables are increased E^s_d is increased and approaches a maximum value when $\theta' = Q_p$ as can be seen from (2). If, on the other hand we decrease the angle Q^o_s the value E^s_d is decreased to a minimum. We can, therefore, account for the efficiency curve of the inductive load falling below the non-inductive as to drop in E.M.F. There is also a drop in current which also varies as the angle is increased. From the diagram using ampere terms $(I\ N)d = I_p - I_s t$

$$I_p = \left[\overline{OF}^2\ \overline{OI_s t}^2 - 2\cos(a + 90^\circ + Q^o_s)\ \overline{OF}\ \overline{OI_s T}\right]^{\frac{1}{2}}$$

$$\therefore (IN)d = \left[\overline{OF}^2 + \overline{OI_s T}^2 - 2\cos(a + 90^\circ + 0^o_s)\ \overline{OF}\ \overline{OI_s T} - I_s T\right]^{\frac{1}{2}}$$

The variable~~s~~ in this equation is Q^o_s as in the equation for the voltage drop. As this angle increases the quantity under the radical increases and reaches a maximum when $(a + 90^\circ + 0^o_s)$ is equal to 180° . This is then also another loss which takes place when the load is inductive.

The third method of testing the efficiency of a transformer if by the use of a calibrated transformer connected with the one to be tested as shown in the scheme Fig. 3 A. The transformer No. 1 is calibrated so that its output at any given instant can be calculated. The output of No. 1 is the input of No. 2 so that the efficiency at any given reading of the wattmeters is equal to $\dfrac{\text{Watt}''}{\text{Watt}' \times \text{Eff. No.1}}$. This method is used a great deal in the testing of the large transformer and where very high voltage is used in the secondary coils. The all-day efficiency of a transformer is equal to the total watt hours output over the total watt hours input during the day of 24 hours.

A transformer in order to have a high allday efficiency may in some cases make it necessary to connect it in such a manner as to lower its efficiency while in operation on a given load. In the transformer under test the efficiency was taken with the coils connected in parallel as shown in Fig. 5, A. This, no doubt, gives a higher efficiency than if they were connected as in Fig. 4, A, on any given load, but if the load during the day was thrown on only for a short period of the day, the increase in copper loss by connecting them in series as in Fig. 4, A would not over balance the core loss if connected as Fig. 5, A.

In order for anyone to determine which connection to use one any 10 to 1 transformer it is necessary to know the no load losses and efficiency with both connections. The losses with both connections for the day's run can then be summed up and the method of connecting which gives the least all day losses is the one to use.

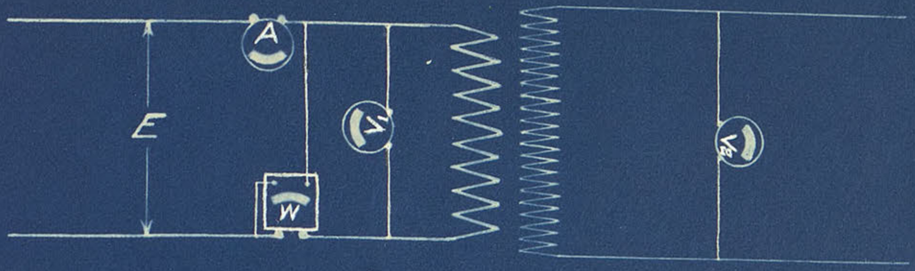


FIG. 1A

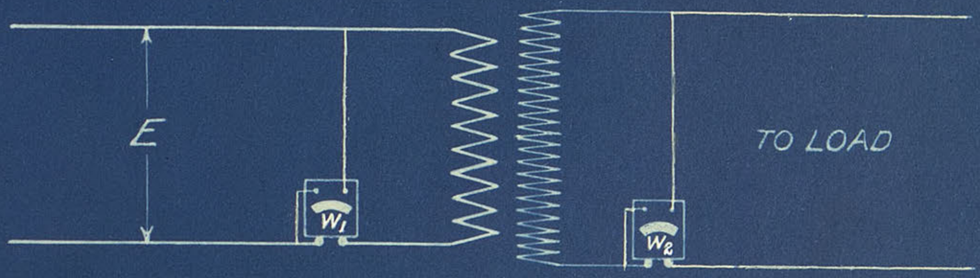


FIG. 2A

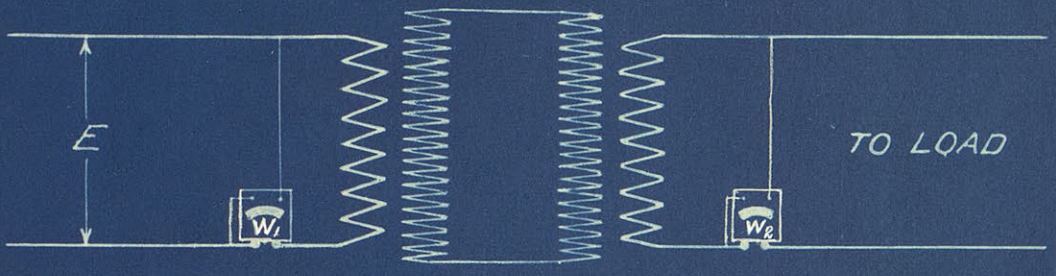


FIG. 3A

FIG. 4A

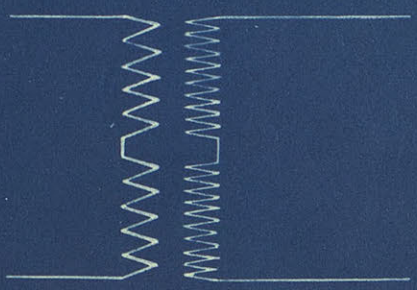
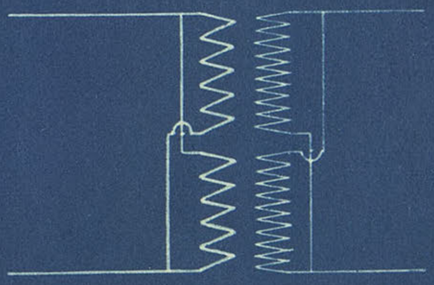


FIG. 5A



EFF. DATA for INDUCTIVE LOAD. --

Impressed Volts.	Primary Watts.	Secondary Watts	Secondary Cos O_s	% Eff.
104	1150	840	.63	85.4
Const.	1530	1315	.787	92.75
	2625	2480	.951	97.3
	3350	3200		97.
	5200	4900		97.

- o -

EFFICIENCY DATA for NON-INDUCTIVE LOAD. ---

Primary.		Secondary.		%
Impressed Volts.	Watts.	Watts.	% Full Load.	Efficiency.
104	1240	1635	20.6	91.25
Constant.	2700	2571	51.1	97.6
	3610	3470	69.6	98.2
	3980	3810	76.25	98
	4660	4450	89.	98
	5000	4825	96	98.3
	5420	5190	104	98.1
	5760	5418	109.6	97.7

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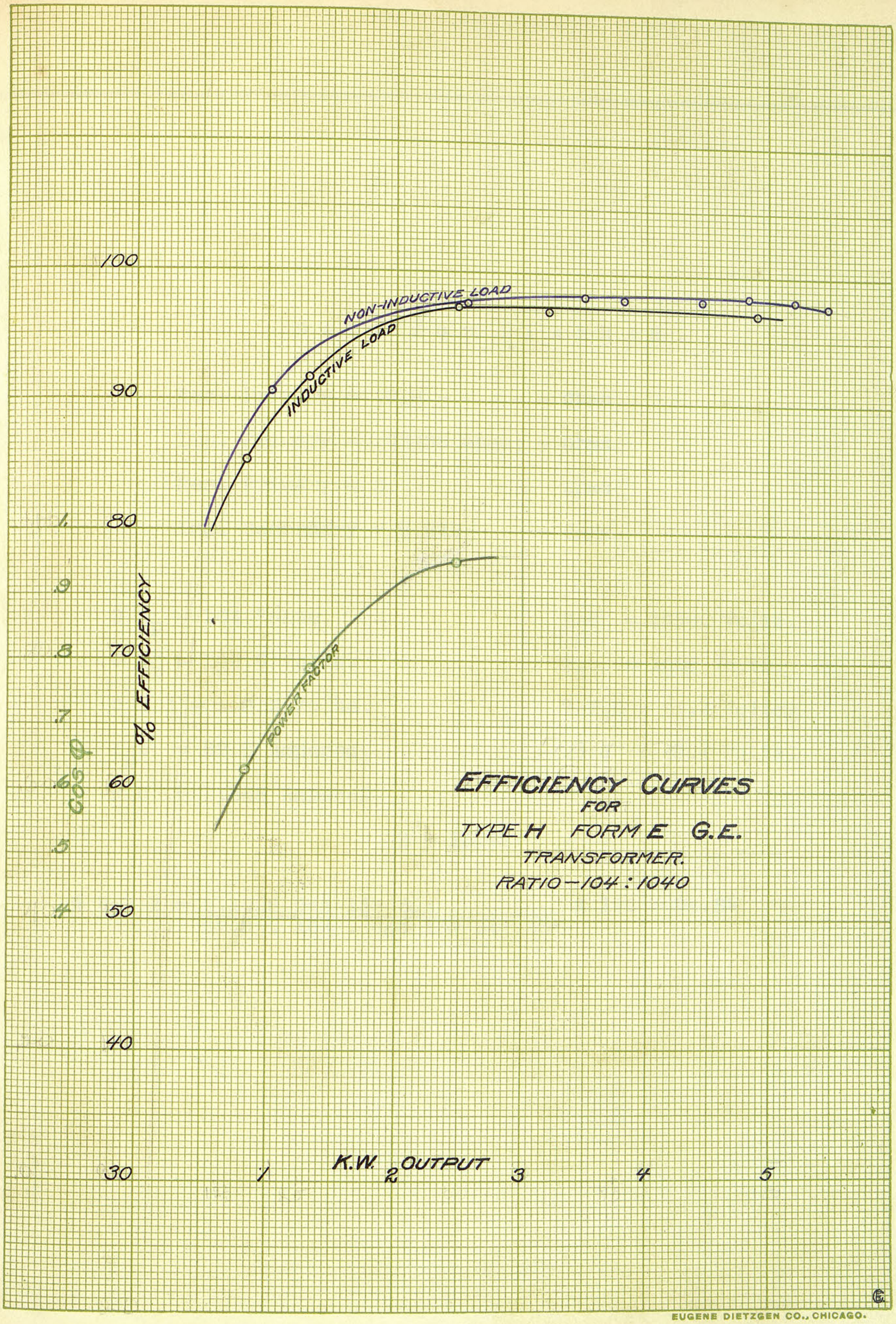

EFFICIENCY CURVES
FOR
TYPE H FORM E G.E.
TRANSFORMER.
RATIO – 104 : 1040
NON-INDUCTIVE LOAD
INDUCTIVE LOAD
POWER FACTOR
% EFFICIENCY
cos φ
100
90
80
70
60
50
40
30
1.
.9
.8
.7
.6
.5
.4
K.W. OUTPUT
1
2
3
4
5

DATA for DIAGRAM.

Res. Primary = .019 - - - - - Ohms;

Imp. Primary = .03435 ~~ohms;~~ - Ohms;

Res. Primary = 3. - - - - - - - Ohms;

Imp. Secondary = 9.682 - - -- Ohms.

$0\ E_p = 104$ Volts.

$0\ E^{\circ}_p = 102.6$ Volts.

$0\ E\ ' = 1.815$ Volts.

$I_p0 = 52.8$ Amperes.

$F\ 0 = 1.345$ Amperes.

$E^{\circ}_s0 = 1056.$ Volts.

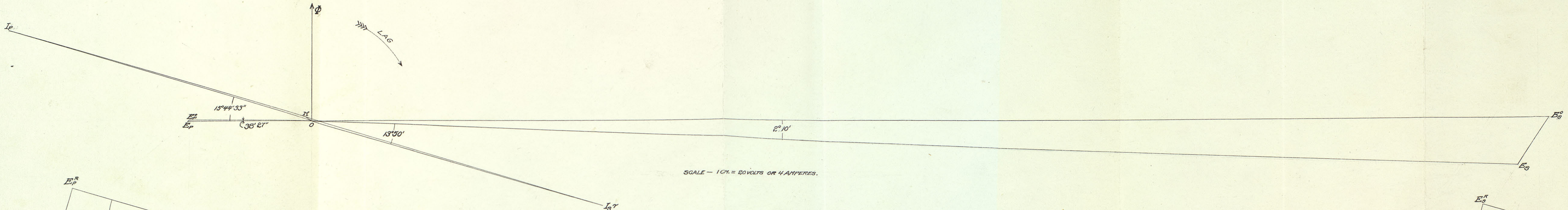
$E_s0 = 1028$ Volts.

$T\ I_s0 = 51.4$ Volts.

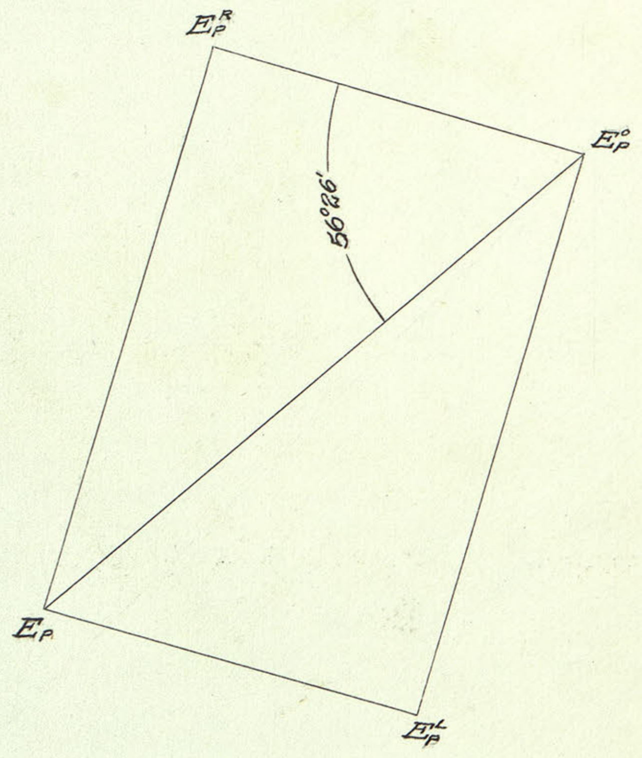
$E''\ 0 = 48.4$ Volts.

$T = 10.28$

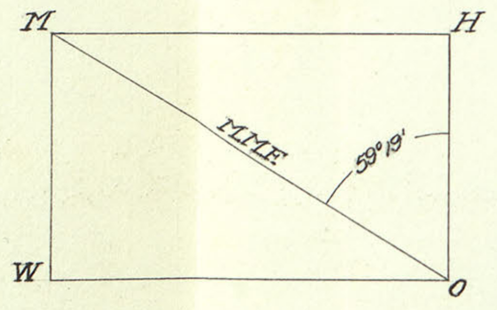
$$\%\ EFF = \frac{5.1028\ \mathrm{Cos}\ 13^{\circ}\ 50'}{52.8\ .\ 104\ .\ \mathrm{Cos}\ 15^{\circ}\ 44'\ 33''} \times 100 = 94.5\%$$



SCALE — 1 CM. = 20 VOLTS OR 4 AMPERES.



SCALE — 5 CM. = 1 VOLT



SCALE — 5 CM. = 1 AMPERE

A

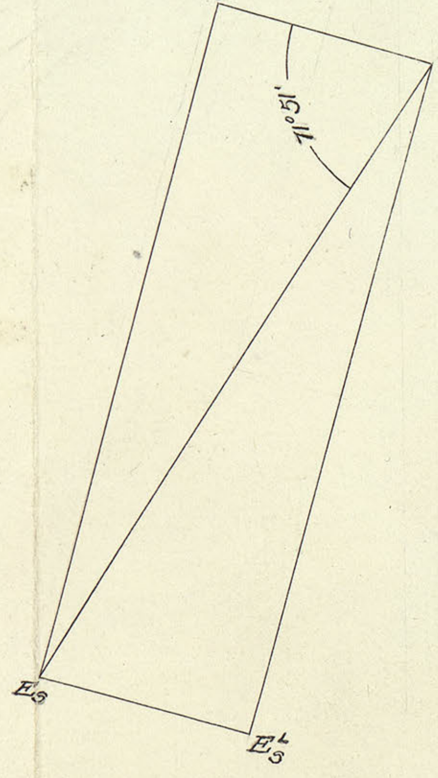
STEINMETZ DIAGRAM

FOR

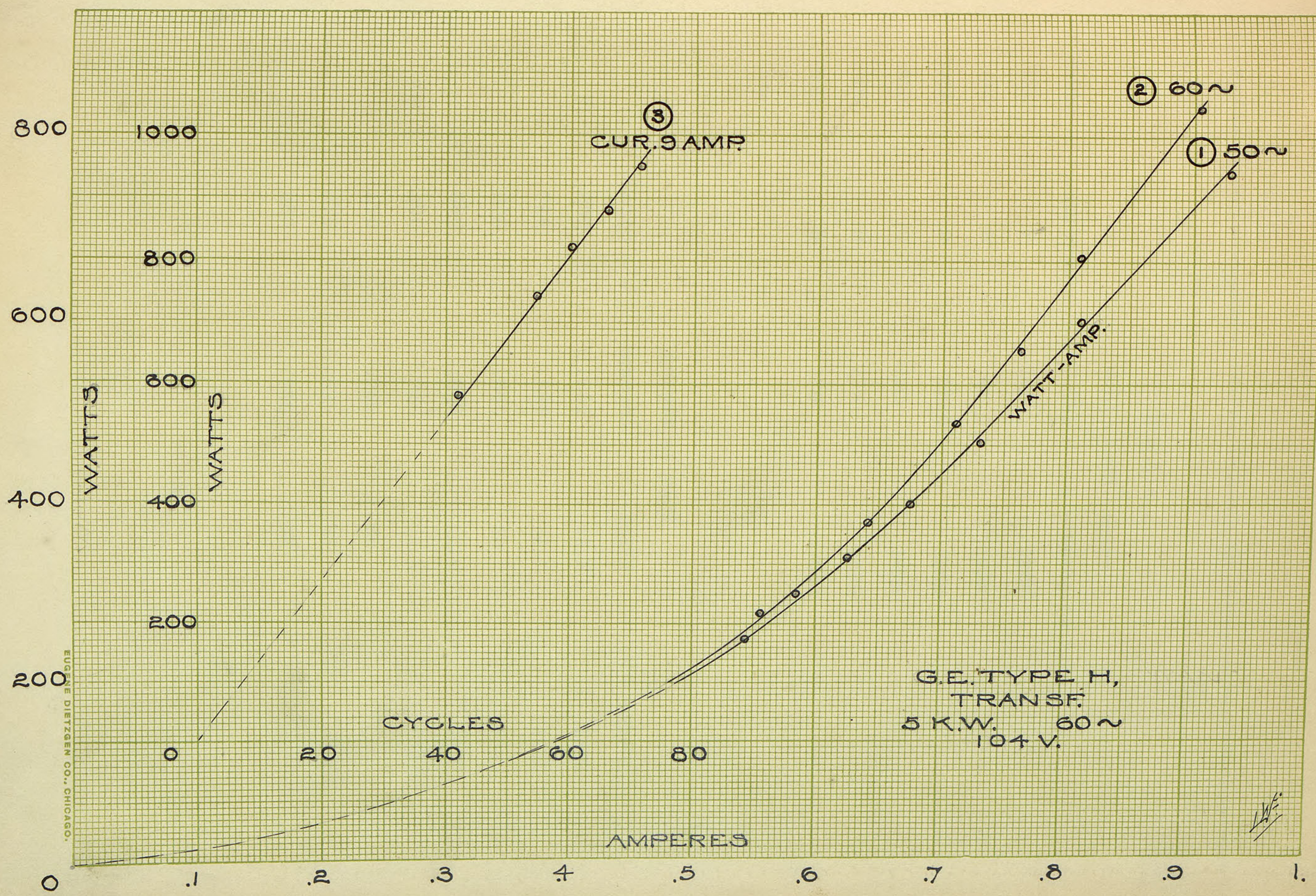
TYPE **H** FORM **E** **G.E.**

TRANSFORMER.

COILS IN PARALLEL



SCALE — 1 CM. = 5 VOLTS


③
CUR. 9 AMP.
② 60~
① 50~
WATT-AMP.
800
600
400
200
WATTS
1000
800
600
400
200
WATTS
CYCLES
0
20
40
60
80
G.E. TYPE H,
TRANSF.
5 K.W. 60~
104 V.
AMPERES
0
.1
.2
.3
.4
.5
.6
.7
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1.
EUGENE DIETZGEN CO., CHICAGO.

D A T A .

CORE LOSS. -----

Watts	Amperes	Volts	Speed (R.P.M.)
820	9	105	1200
740	9	96.5	1098
750	9	96.8	1098
950	9	121	1416
880	9	113	1320
580	9	75	840

CHANGE of FLUX.

Watts	Amperes	Volts	Speed.
250	.544	43.5	1200
280	.555	45.5	1200
300	.585	50	1200
380	.642	60.5	1200
490	.71	71.8	1200
570	.762	80	1200
670	.81	89	1200
830	.905	102	1200

- # -

CORE LOSS.

Fig. 3, Plate P is the scheme of test.

Upon the preceding curve sheet three curves are represented relating to the iron loss in a transformer. The data for (1) marked 50~ was obtained by holding the frequency constant and varying the flux or voltage over the primaries, with the secondary open circuited.

The equation for hysteresis and eddy currents as already given are,

$$Ph = V\ f\ n\ Bm^{1.6} X\ 10^{-7}$$

$$Pe = k\ V\ f^2 l^2 Bm.$$

From these it may be seen that the iron loss in a transformer does not vary directly with the flux but as the 1.6 power and square respectively. This accounts for the watts increasing in a much greater ratio than the current. The curve practically follows that of a parabola.

Another factor which enters into the core loss is the frequency. With this the hysteresis loss varies directly, while that due to eddy currents varies as the square of the frequency. If the same method of test is used and the frequency held constant at 60~ curve (2) results and shows the relation of iron loss to the current. The energy lost by hysteresis appears in the form of heat and depends greatly upon the hysteretic quality of the iron. Soft Norway iron gives the smallest hysteretic loss but it will not stand so great a flux density, as stamped steel castings which are almost universally used in the best armatures. Sometimes it is found that after a few months' use the core loss of a transformer has increased about 100%. This is generally caused by an effect called ageing of the iron, which results from overheating the core and is sometimes of considerable importance.

In the best commercial transformers this is remedied by keeping down the heat. Iron which has been aged can be brought to its natural condition by annealing.

To show more clearly the effect of frequency upon core loss, curve (3) was experimentally determined. In this test the flux in the core was held constant and the frequency varied. By changing the frequency this increases the cyclic changes of flux and at the same time rapidly increases the eddy current loss. Eddy currents are caused by the difference of magnetic potential between different parts of the iron core. Such currents are a waste of energy and if they are not prevented will cause excessive heating in the iron. Laminating the iron core serves the purpose of introducing resistance in their path and the resulting loss decreases as the square of the thickness of the laminae. In a great many good transformers the coating of oxide upon the laminae is relied upon for insulation.

Let e d be the pressure generated in the disc. and r d = elect. resistance of the disc. Then the loss due to eddy currents equals $\frac{e^2d}{r\ d}$. The E. M. F. e d generated in the disc varies as the number of cycles and the number of lines entering the disc, since it depends upon the differences of flux distribution caused by cyclic changes. If the thickness of the disc is increased the flux entering the disc increases in the same proportion. Hence r d is inversely proportional to the thickness of the disc. $\frac{e^2d}{r\ d}$ then varies as the cube of the thickness of the disc. But the number of disc is inversely proportional to the thickness of each for the same amount of iron, hence the total heating due to eddy currents when the discs are completely insulated decreases as the square of the thickness of the laminae.

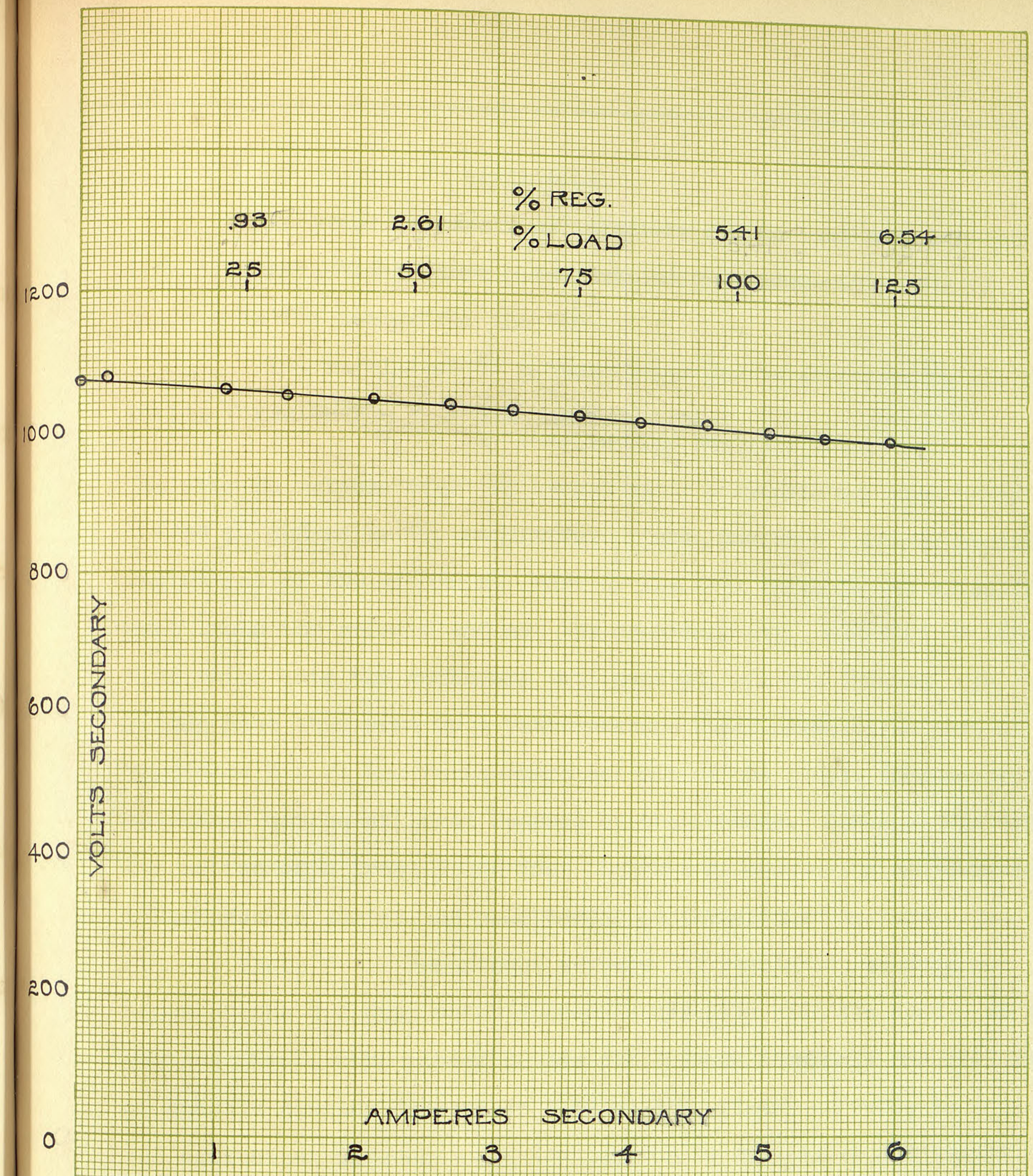
An important effect that change of frequency has upon the transformer is variation of impedance; this is directly influenced by cyclic change.

$$\text{Imp} = \sqrt{R^2 + 2\pi f L^2}$$

L = inductance, f = frequency, R = resistance

REGULATION DATA.

PRIMARY.			SECONDARY.	
Amperes	Volts	Watts	Load	Volts.
5.94	1000	5.950	59.9	104
5.46	1005	5450	55.2	104
5.04	1010	5010	50.8	104
4.59	1020	4630	46.8	104
4.07	1027	4120	41.8	104
3.6	1032	3700	36.8	104
3.1	1035	3120	31.8	104
2.65	1045	2750	27.2	104
2.1	1050	2200	22.1	104
1.5	1055	1680	16.3	104
1.05	1060	1180	11.6	104
.2	1075	600	6.5	104
.0	1070	120	1.35	104



G.E. TYPE H 5 K.W.
TRANSF. REG.
CURVE.

Regulation.

In order to render satisfactory service and maintain long life to incandescent lamps close regulation is desirable. Fig. 2, Plate P is the scheme for the test.

The regulation of a transformer may be expressed by the following formulae $\frac{V - V'}{V}$ V = Volts no load

V' = volts over sec. full load.

The drop in voltage over the secondary of a transformer upon being loaded is caused by two conditions, first; magnetic leakage; second; resistance of the windings. Part of the flux which is set up in the core links the primary and not the secondary coil, and part of the flux which cuts the secondary coil does not cut the primary. In either case this sets up a back pressure which neutralizes part of the impressed E.M.F. and furthermore not all of the E.M.F. induced in the secondary can be utilized because of the leakage. Leakage flux effects the action of a transformer just the same as connecting an equivalent inductance in series and considering no transformer leakage. See Fig. 1, Plate P. Resistance affects the regulation because because of the C R drop which increases directly with the load. An impedance which, when placed across the primary terminals and will allow an exactly similar current to flow as the primary current, is called the equivalent impedance and its components are called equivalent resistance, and equivalent reactance. From this definition and the sector relations it can be proven that the equivalent resistance varies directly as the resistance of the secondary and inversely as the square of the ratio of transformation. (See Sheldon's A.C.Machines) p. 98)

R = equiv. res. of secondary;
X = equiv. res. reactance of secondary;
r = ratio of transformation.

$R = \frac{R_s}{r^2}$ $X = \frac{X_s}{r^2}$

then let V_s = Volts over secondary;

and E_s = sec. volts generated;

s = Ind. of secondary;

φ = of lag of I_p behind E_p.

$$V_s = r\left[E_p - I_p\left(R_p + \frac{R_s}{r}\right)\cos\varphi - w\left(L_p + \frac{L_s}{r^2}\right) I \text{ Sine } \varphi\right]$$

$$\text{Regulation} = \frac{r E_p - V_s}{V_s}$$

By increasing the amount of iron to prevent leakage the core loss is increased. A liberal use of copper in the windings will aid regulation to a great extent, but the working condition of the plant and cost of power limit the extent to which low core loss can be sacrificed for regulation. Where power is cheap the matter of core loss is not so important and good regulations under such conditions should be secured.

The guaranteed regulation of a good commercial transformer ranges from 1.5 to 5% according to their respective capacities, namely, 25 K. W. and 500 watts.

Inductive loads effect transformers the same way as any other alternating current apparatus. It causes excessive heating if the transformer is not of sufficient capacity. Aside from this the ohmic drop and leakage flux, which is the result of increased current, causes bad regulation. The power factor upon inductive loads is generally very changeable, Since induction motors are the most common form of load and which cause such variations where large motors are used, at various loads, their change of power factor sometimes effect the whole system. This is very objectionable where such motors are operated upon incandescent lighting circuits for reason that it causes "blinking" of the lights. Compensators cannot easily regulate for such sudden variations of voltage.

DATA.

CHANGEof FLUX.

Watts	Amperes	Volts	Speed.
890	1.3	101	1000
760	.93	94	1000
600	.81	80.5	1000
470	.73	68.5	1000
400	.675	67.5	1000
340	.625	52.5	1000
230	.30	40	1000

Impedance Test Data.

Watts	Volts	(Amperes - - Primary)	(Amperes - - -Secondary.)
30	10	2.05	20.5
39	14	2.43	24.9
42	29	2.99	30.2
72	35	3.6	36.3
91	39.6	4.03	40.4
95	41	4.11	41.2
112	44	4.53	45.75
122.7	47	4.89	49.1

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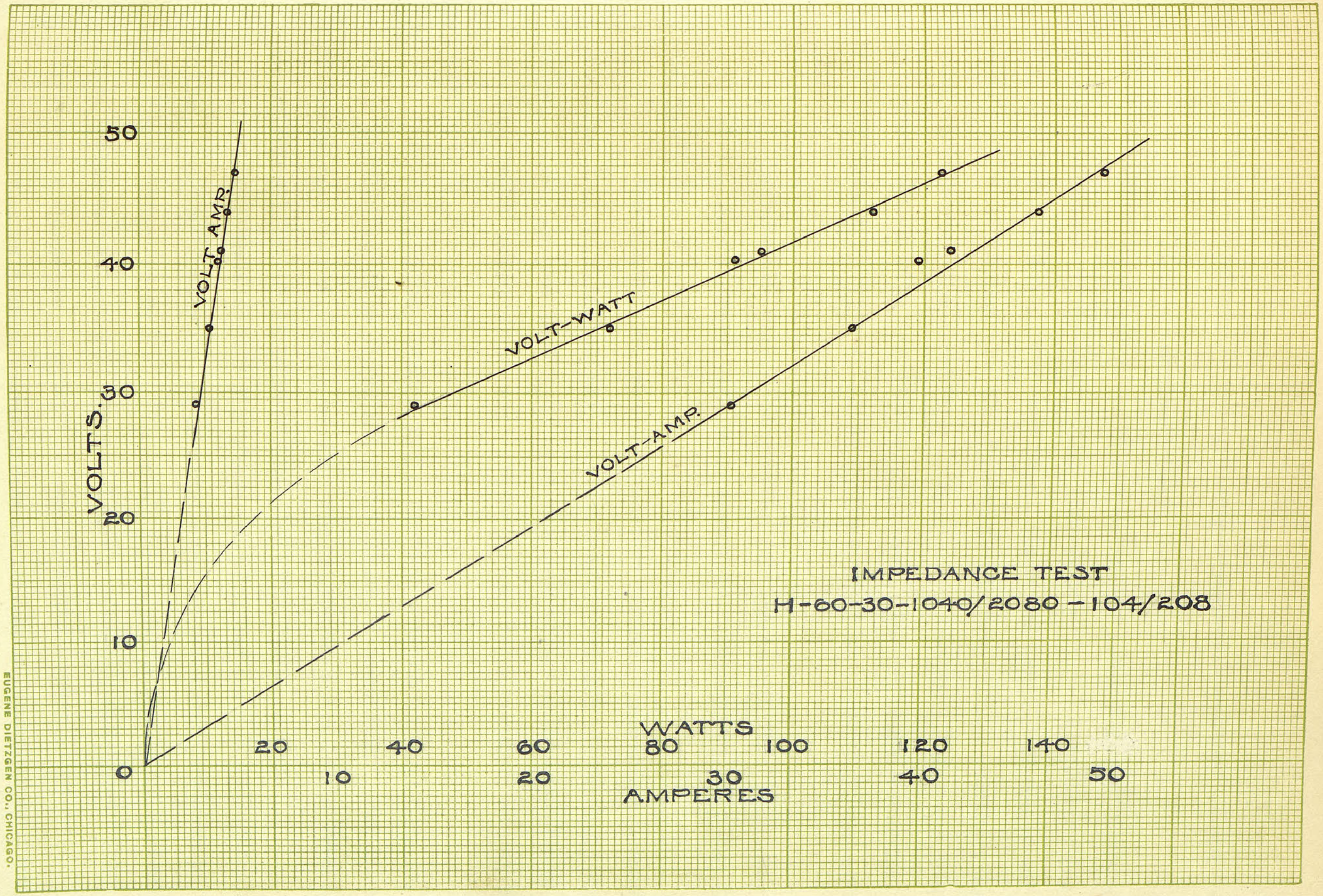


IMPEDANCE TEST
H-60-30-1040/2080-104/208

Impedance Test.

Fig. 4, Plate P shows the method of measuring the impedance of both windings of a transformer linked only with the leakage flux. The low tension mains are ~~are~~ short-circuited because it would be more difficult to measure the impressed voltage if the reverse connections were used. The generator from which current was taken was run at normal speed with its fields unexcited. The residual magnetism was sufficient in this to cause a current of 20 amperes in the secondary.

Gradually raise the exciter voltage to get full load current of the transformer. At each step take simultaneous readings of Watts, volts, and amperes.

The impedance test is important because when transformers are operated in parallel the load divides inversely as their impedances, i.e. the greatest load will fall upon the transformer which has the least impedance. This is made clear by inspection of the formulae $C = \frac{E}{Imp.}$.

Regulation depends for a greater part upon impedance. If close regulation is desired a low impedance is necessary. The impedance voltage varies from 1 to 4%. The impedance watts range from 1 to 1-1/2% of the total capacity of the transformer.

The impedance volts shown by this test is 4.52% of normal volts, and the impedance watts were 2.48% of the total capacity of the transformer (5 K. W.). The volt ampere curve should be a straight line, because the current varies directly with the impressed volts, since the inductance, resistance and frequency remain constant.

The volt watt curve should be nearly a parabola for reason that the leakage flux varies with the load and for all practical purposes the watt loss varies as the square of the leakage flux.

Consider the equations ,-

$$Pe = K\ f^2 l^2 Bm^2$$
$$Ph = V\ f\ n\ Bm^{1.6} X\ 10^{-7}$$

From these equations it may be seen that the watts core loss varies as the 1.6 power and square respectively of Bm when everything else remains constant. Since in this test only leakage flux is dealt with it is valuable in determining the inductance of the transformer and is treated accordingly in the Steinmetz diagram.

Coml. Use of Transfs.

Among the many methods of power transmission, that by means of high voltage electric transmission has gained predominance where the distance concerned is very great. A great deal has been done to improve the efficiency of transmission under such conditions, and an important item to be considered is the proper use of transformers. A common condition to be met with in practice is to supply from an available source of power, a certain amount, over a given distance, at the cheapest possible price both for installation and the power to be consumed. The source of power generally available in the west is a small swift stream of water which can be directed into penstocks and delivered to water turbines. These turbines may have either vertical or horizontal shafts. For high heads the generator is generally directly connected to the turbine, and for low heads it is commonly belted. The generator voltage is stepped up to high pressure, (depending upon the distance), and again stepped down at the point of distribution to low voltage.

In the United States very few three phase transformers are used, because it is found that the extra cost of construction, overbalances the saving of iron, part of which is common to the three phases. Where the three phase system is used throughout the individual transformers are connected in the different phases either Y or Δ See Fig's 2 & 3, Plate S .

If the delta connection is used the transformer has to be wound for full line voltage and if the Y connection is used the transformer need only be wound for 57.7% of the line of voltage. Consider 3 transformers are connected as in Fig. 2, Plate S. At any instant the current flows in on one wire and out at the other two. Each wire

S

FIG. 1A.

STANDARD POLARITY.

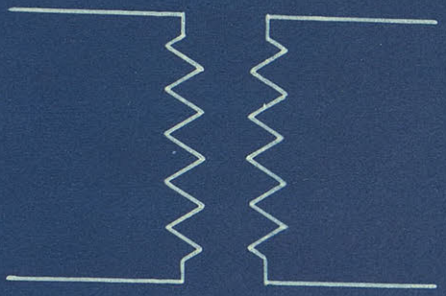


FIG 1B

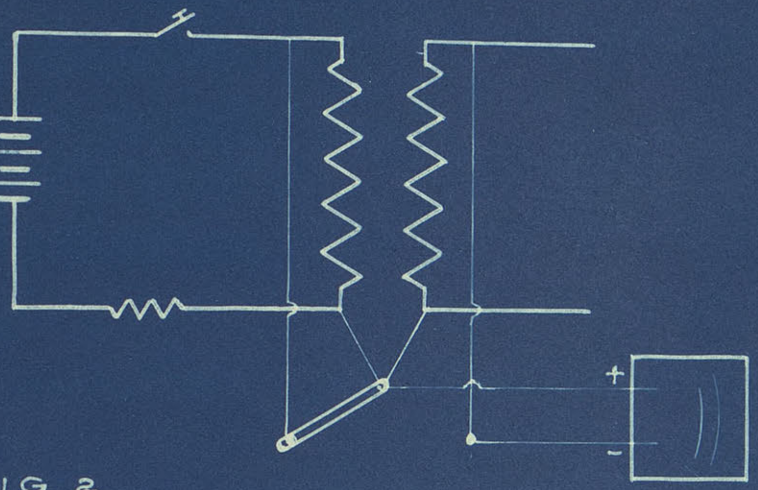


FIG. 2.

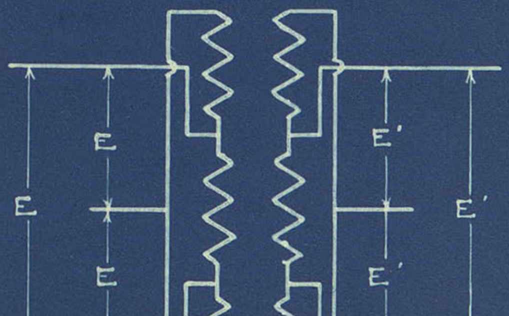
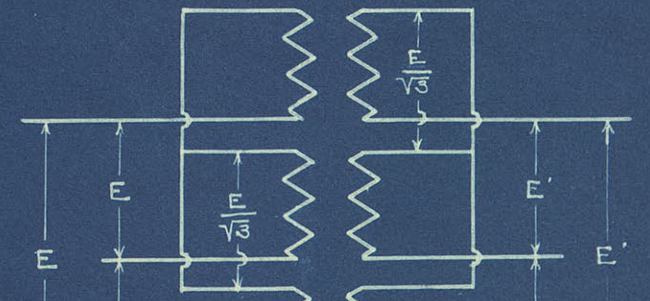


FIG. 3.



LWF.

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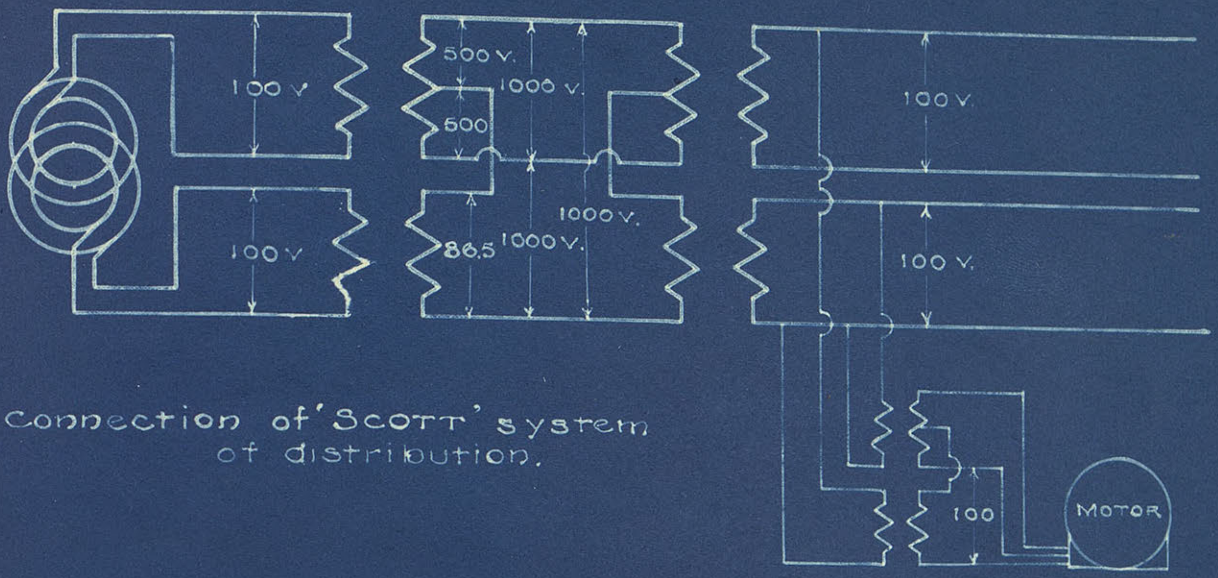
FIG. 1.



Connection of 'Scott' system of distribution.

FIG. 2.
Delta connection.

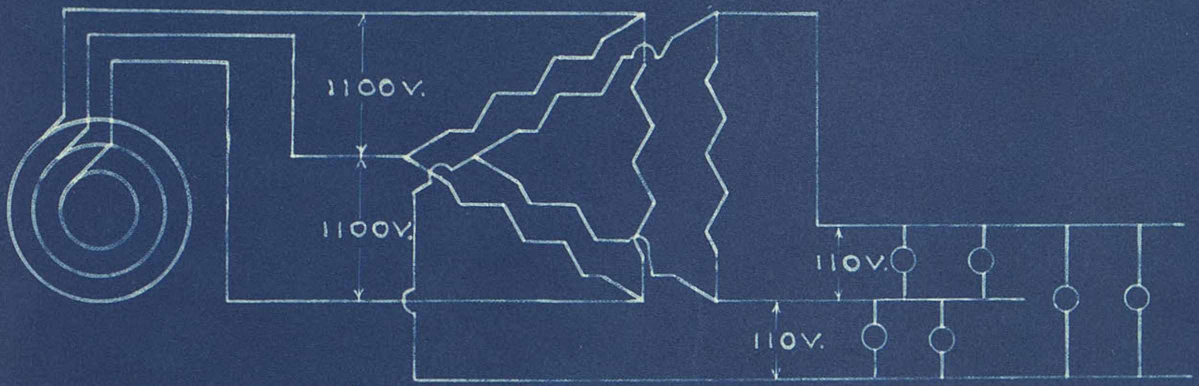
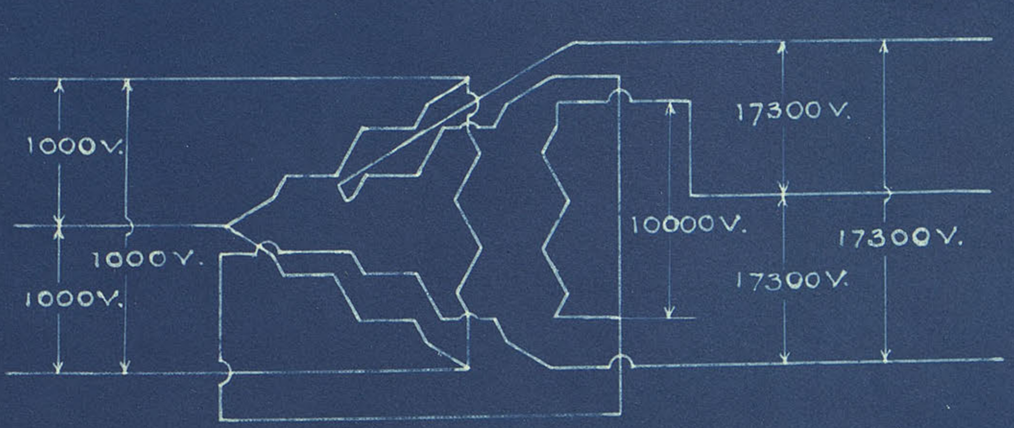


FIG. 3.
Primary 'Delta', Secondary 'Star'.



LWF.

carries $\frac{1}{\sqrt{3}}$ amperes. This current results from subtracting the current in each coil at 120°, or adding them at 300°. The line wires are connected over each coil which makes it necessary to wind the coil for full line voltage. Fig. 3, Plate S shows the star connection in in which the line wires are connected over two coils at 120° apart. In this case the resultant E.M.F. over each coil is $\frac{E}{\sqrt{3}}$ volts because the E. M. F..'s subtracted at 120° or added at 300°. The current in each coil has the same value as that in the line wires. Whatever connection is used the power in any coil remains the same.

Two phase generators are also used for long distance transmission work. Their chief advantage lies in the fact that the voltage may be stepped up to three phase by means of the Scott connection, transmitted over the given distance then stepped down to 2 phase through the Scott transformer and delivered for power and lighting. See Fig.1, Plate J.

Type H transformer has a ratio of 10 : 1 when connected in parallel. This ratio is generally considered in a much broader sense. 100 : 10 or 1000 : 100. The first thing to be considered by station managers when connecting up banks of transformers is their polarity. Standard polarity is obtained by winding the coils of a transformer with always a fixed relation between the primary and secondary, and more important, a fixed relation between the primary windings of two different transformers. A standard polarity is established so that in connecting up a transformer it is unnecessary to test for polarity. All transformers are given the polarity test before being put on the market.

Figure 1, A and 1, B, Plate S. show the scheme for the polarity test. This test is easily made when the transformer is connect-

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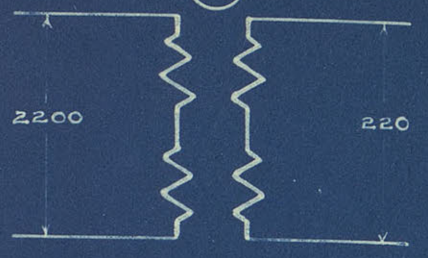

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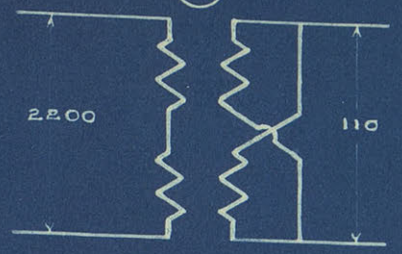

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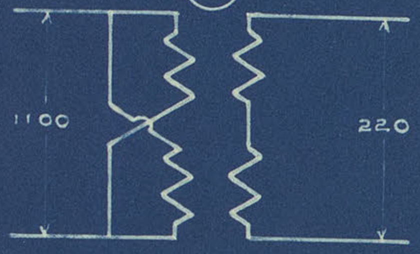

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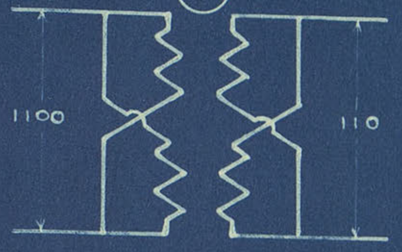

COMPENSATOR CONNECTIONS

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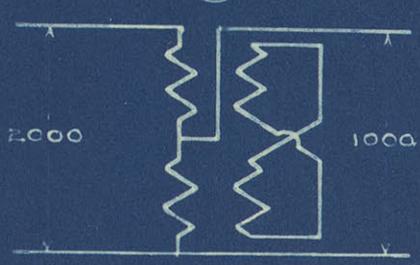

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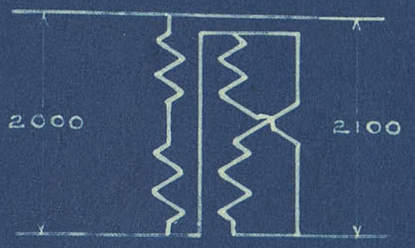

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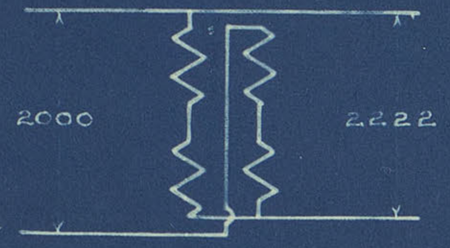

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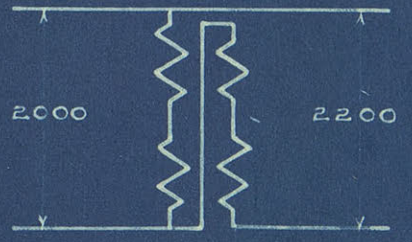

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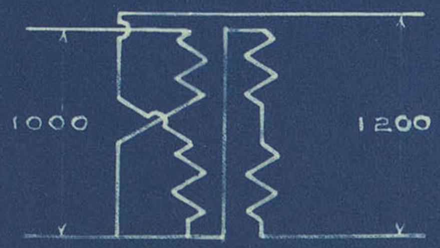

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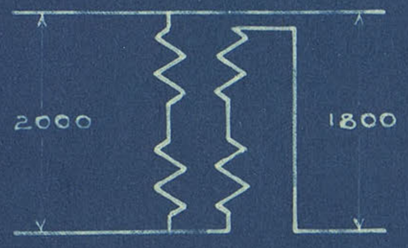


LWF

ed for measuring the resistance of its windings. With the direct current flowing through one of its windings connect a voltmeter across the terminals so as to get a positive deflection. Then transfer the potential wires to the corresponding terminals of the other winding. Next break the circuit in the first winding and if a positive kick of the voltmeter is obtained the transformer is of correct polarity.

The direct current in the primary sets up a flux in the core and any change of current induces an E.M.F. at 180° from the impressed, Now suppose the corresponding terminals of the voltmeter are connected to the other winding and the primary current is broken. Instantly the flux tends to die away and an E.M.F. is induced in the secondary which produces the same polarity as the other winding when the direct current was connected to corresponding terminals.

In each winding of the G. E. type H transformer there are two coils and by means of a connection block in the upper part of the case these may be connected for different voltages. (a) of Plate (L) shows both coils connected in series. In (b) the primaries are connected in parallel and the secondaries in series. (c) shows the connection for the primaries in series and the secondaries in parallel, and in (d) both coils are connected in parallel. For whatever connection used the capacity of the transformer remains the same as may be seen by comparing (a) and (d). The latter connection is capable of carrying twice the amount of current as the former with the same rise of temperature.

By knowing the polarity of transformers some very convenient compensator connections can be made when needed. Fig. 6 of Plate (L) shows a connection of type H by means of which the line voltage can be decreased 10%, and Fig. 4 shows a corresponding increase. Fig. 2

boosts up the line voltage and Fig. 3 shows a finer degree of adjustment. All these connections are useful to station managers if properly used, and by means of two transformers an experienced person can obtain almost any voltage desired.

The temperature rise of a transformer should not exceed 50° Cwt. above that of the surrounding air since the larger sizes should radiate about 600 watts per sq. in. of surface.

Small transformers usually have enough exposed surface to radiate the heat due to its losses, but since the size increases much faster than the radiating surface artificial means of cooling has to be employed in the larger sizes. These are as follows:

Air Cooled. Water Cooled. Oil Cooled.

Small lighting transformers up to 100 K.W. capacity are generally oil cooled. In these the transformer oil is is poured into the coils and the transformer case is filled. This oil covers the core and windings thus serving for an insulating material, and tends to remedy any defective insulation. The natural circulation of oil tends to equalize the temperature and carries this heat to the case where it is dissipated.

Very large transformers have in addition to the natural circulation of oil, a number of pipes coiled in the oil through which water is forced. These are the water cooled types and by this means the desired temperature can be maintained. Other large substation transformers are cooled by a forced circulation of air in case water is expensive.

Very high potential wires are generally subject to a small brush discharge which forms ozone and deteriorates the insulation sometimes very rapidly. This is the chief objection to the ail cooled transformers and is very serious for potentials over 10,000 volts. This decaying action does not exist in the oil cooled type, (See Electrical Review, Feb.18,'05). In every case where artificial means are employed for cooling transformers this power is charged against the same when considering the input to calculate the efficiency.

Transformers have an extensive use in connection with long distance transmission lines. For such lines transformer houses are constructed outside the city and the voltage stepped down to low tension for local use. In case a separate transformer station cannot be provided it is always best to install the transformers upon insulated supports on the second floor. Lighting protection should be amply provided for in order to save burnouts. Complete lightning protection must consist of a choke coil and lightning arrester. The former should have a high equivalent air gap, and the latter a low one. In most cases inductance coils should be placed on the high tension side between the lightning arrester and transformer except when the Horn arrester is used. With this the same is found to be unnecessary. Aside from the direct lightning strokes a more common and serious trouble is the rise of line voltage due to induced charges from heavily charged clouds. Upon certain 2200 Volt lines such trouble has occured and upon examination of the coils it was found that the burnouts occured between the two high tension lines, and not between the primary and secondary coil as supposed up to that time. The remedy for such trouble is to place a spark gap across the connection board of the transformer. This spark gap is set so as to discharge at the desired potential and thus save the transformer even at the expense of the station fuse. Transformers should not be placed inside of buildings except at central stations where special buildings are generally provided and should have at least 6 inches clearance of air space around the case.

In computing the size of transformers to be used on inductive loads the power factor has to be taken into account. Suppose 4 K. W. is to be used with a power factor of .8. The required capacity of transformer used should be $\frac{4000}{8} = 5000$ watts.

For induction motor it is usual to install the same kilowatt capacity of transformer as the horse power rating of the motor. Lighting transformers of moderate sizes range in capacity from 500 watts to 25 K.W. and have an efficiency of 93.2 and 98.8% respectively.

It is always best to install a large transformer in the place of several smaller ones, both from the point of initial relative cost and increased efficiency.

The following page shows the transformer distribution in the city of Manhattan. Most transformers are of the G.E. Type H. with 2080 Volt primaries and 110 volt secondaries. The power station as indicated on the map consists of one 175 K.W. generator which is wound for 2080 volts no load, and a current of 39 Amperes full load. The primary lines are carried on 42 feet poles and are 125 feet apart within 5 locks from the station. The centre of distribution is at the corner of Pointz Avenue and 3d Street. The current is carried on No. 3 wires to the point of distribution and No. 6 wires are used for delivering power within 3 blocks of the centre of distribution. All other primaries are No. 8 wires. The wiring conforms to the Fire Underwriters rules. The sizes of the transformers range from 2 K.W. to 30 K.W. The centre of distribution might have been located several blocks west to allow for growth in the business district of the city, and if, in the place of the three trnsformers between Houston Street and Pointz Avenue, of 7, 7, and 30 K.W. capacity respectively, one 50 K.W. were installed, the latter would be more efficient than the present arrangement. The efficiency of the three combined would be approximately 97.4% at full load, and the efficiency of 1 50 K.W. would be approximately 98.8%. (See Foster P. 350.) Three more directly west of 15, 7.5, and 5 K.W. capacity respectively could be replaced by one 40 K.W. also the 4 K.W. and 10 K.W. between 5th and 6th street could be replaced by one 16.5 K.W. where the 10 K.W. stands. It would also be economical to combine the two 16.5 K.W. on Pointz Avenue with the 5 K.W. directly north into one transformer of 40 K.W. capacity. In the same manner the capacities of 4, 4, and 5 K.W. respectively between Osage and Freemont streets could be replaced by one 16.5 K.W. As a whole the transformer distribution for lighting purposes could not easily be improved except by replacing the smaller transformers as the needs for larger capacities grow.

P.

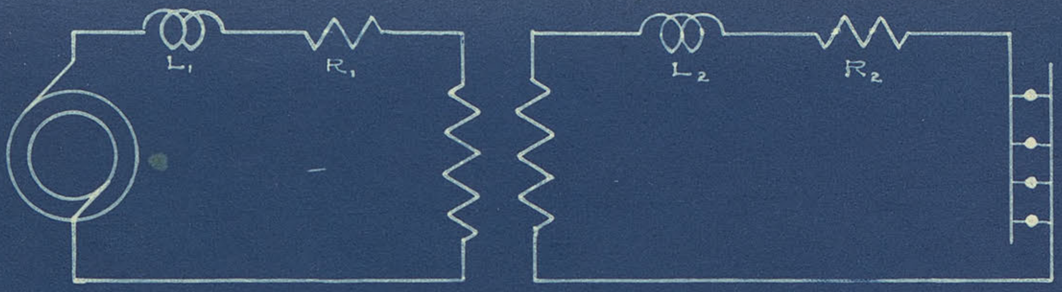


FIG. 1.

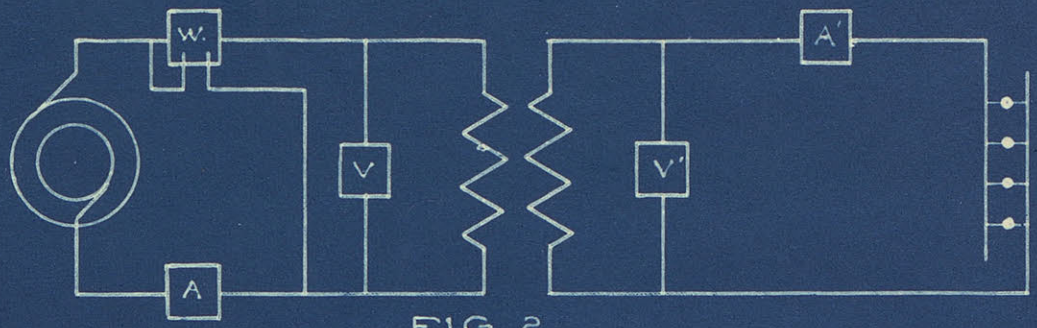


FIG. 2.

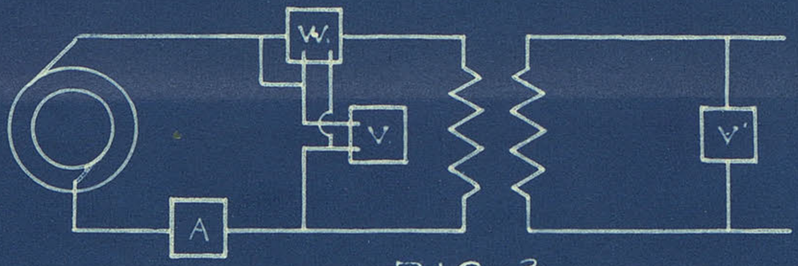


FIG. 3.

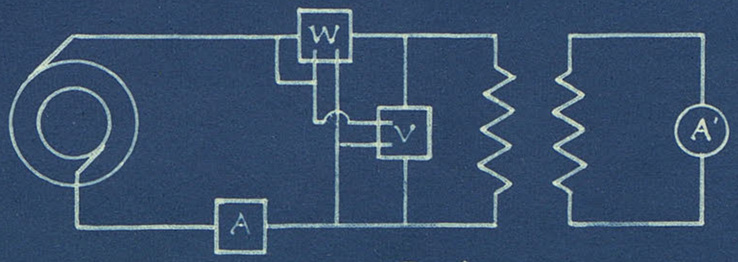
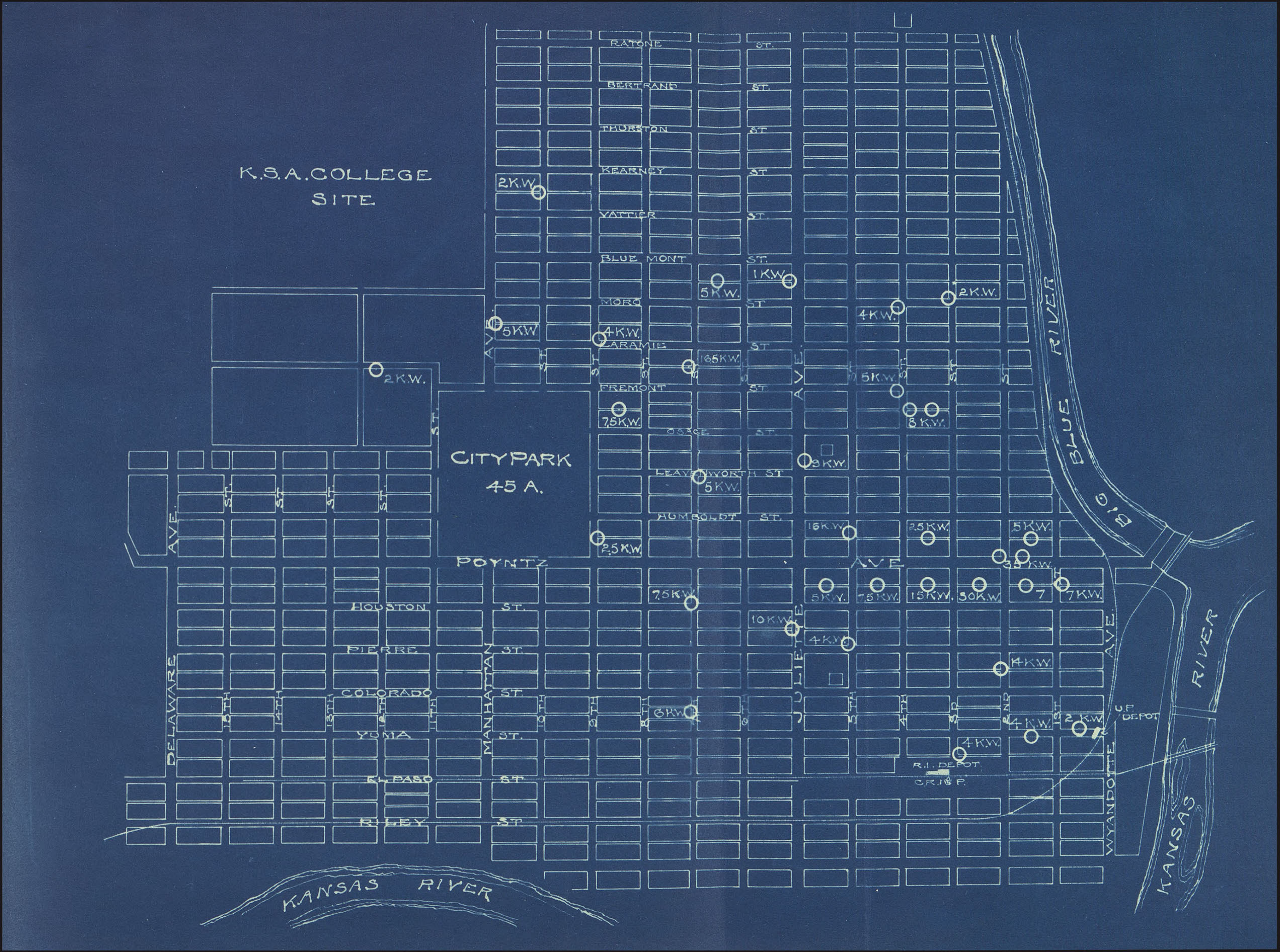


FIG. 4.

LWF


K.S.A. COLLEGE
SITE
CITY PARK
45 A.
RATONE ST.
BERTRAND ST.
THURSTON ST.
KEARNEY ST.
VATTIER ST.
BLUE MONT ST.
MORO ST.
LARAMIE ST.
FREMONT ST.
OSAGE ST.
LEAVENWORTH ST
HUMBOLDT ST.
POYNTZ AVE.
HOUSTON ST.
PIERRE ST.
COLORADO ST.
YUMA ST.
EL PASO ST.
RILEY ST.
DELAWARE AVE.
MANHATTAN AVE.
JULIETTE AVE.
WYANDOTTE AVE.
BIG BLUE RIVER
KANSAS RIVER
KANSAS RIVER
U.P. DEPOT
R.I. DEPOT
C.R.I.& P.
2 K.W.
2 K.W.
5 K.W.
1 K.W.
2 K.W.
4 K.W.
5 K.W.
4 K.W.
165 K.W.
5 K.W.
7.5 K.W.
8 K.W.
9 K.W.
5 K.W.
16 K.W.
2.5 K.W.
5 K.W.
2.5 K.W.
35 K.W.
7.5 K.W.
5 K.W.
7.5 K.W.
15 K.W.
30 K.W.
7
7 K.W.
10 K.W.
4 K.W.
4 K.W.
6 K.W.
4 K.W.
2 K.W.
4 K.W.