DIRECT CURRENT COMPOUND WOUND BALANCERS.

A. C. Lanier.

Several articles have appeared in the Technical Press on the theory and performance of direct current balancers*; compound wound balancers, however, have not received the attention their relative importance would seem to justify. This has suggested the publication of the following simple analysis, worked out some time ago in connection with the development of a line of such equipments.

With compound wound sets, the voltage balance between neutral and outers is maintained through the inherent adjustment of field flux in motor and generator, so that the induced electromotive force less the internal voltage drop in the generator is practically constant and equal to the induced electromotive force, plus the interna voltage drop in the motor. This adjustment of flux is brougt about by differential action of the series field in the motr, and cumulative action in the generator; obviously the regultion of the set with shift of unbalanced load from one side of eutral to the other is inherent.

Several schemes of connections are shown diagramatically in Figures 1, 2 3 and 4.

* "On Direct Curret Balancers" by A.E. Kemerlly and S.E.Whiting- Electrical World, nuary 7, 1905.

* "Regulation and ompounding of Lighting Balancers" by Budd Frankenfield Electical World, December 23, 1905.

* "Direct Cureent Ompensators for Balancing Electric Cirruits" by H.M. Biebel, Wester Electricial, February 23, 1907.

The series fields, when connected straight (Fig.1) have a slight differential action running light, when crossed (Figs. 2 & 3) the effect is slightly cumulative, while with series fields connected in the neutral (Fig. 4), the machines operate light as shunt motors. The action of the series field on no load, is negligible in any case. With series fields crossed, the burden of compounding on load, is shifted somewhat from motor to generator: There is less rise in speed with increasing load than with either of the other connections shown, a decreased tendency to instability, and other conditions permitting a corresponding increase in safe momentary overload capacity. With shunt fields tied to the neutral (Figs. 2 & 3) rheostatic adjustment of voltage balance is available; two frequently used methods of disposing shunt field rheostats are shown. Obviously other combinations of series and shunt field connections are available.

VOLTAGE REGULATIONS.

Let E, E_m, and E_g =Voltage across outers, across motor and generator terminals respectively.

e_l, e_m, e_g =Induced volts running light and in motor and generator loaded, respectively.

e_b, e_{bm}, e_{bg} =Voltage drop across positive and negative brushes, running light, motor and generator respectively.

I_l, I_m, I_g, I_n =Amps. running light, motor armature, generator armature and in neutral wire respectively.

r_a, r_s =Resistance of armature and of series field in ohms.

ϕ_l, ϕ_m, ϕ_g =Flux in maxwells entering armature per pole, running light, under loads as motor and as generator respectively.

R_l, R =Speed in revolutions per minute running light, under load.

p, p' = Pairs of poles per machine, pairs of armature circuits.

N_a = Number of armature surface conductors.

$100\ p_c$ = Percent over compounding.

For balanced load, set running light:

$$E = 2e_1 + 2\ I_1\ (r_a + r_s) + 2e_b \qquad (1)$$

$$e_1 = \frac{E}{2} - \left[I_1\ (r_a + r_s) + e_b \right]$$

$$= p\ \phi_1 \frac{N_a}{p'} \frac{R}{60}\ 10^{-8} \qquad (2)$$

For unbalanced load, set supplying unbalanced current to neutral wire.

Motor induced e.m.f., $e_m = E_m - \left[I_m\ (r_a + r_s) + e_{bm} \right]$ (3)

$$= p\ \phi_m \frac{N_a}{p'} \frac{R}{60} \cdot 10^{-8}$$

$$\text{or } R = \frac{6\ e_m \cdot 10^{-9}}{p\ \frac{N_a}{p'}\ \phi_m} \qquad (4)$$

Generator induced e.m.f., $e_g = E_g + \left[I_g (r_a + r_s) + e_{bg} \right]$

$$= p\ \phi_g \frac{N_a}{p'} \frac{R}{60} \cdot 10^{-8} \qquad (5)$$

$$\text{or } R = \frac{6\ e_g \cdot 10^{9}}{p\ \frac{N_a}{p'}\ \phi_g} \qquad (6)$$

$$E = E_m + E_g \qquad (7)$$

For flat compound $E_m = E_g = \frac{E}{2}$ (8)

For over-compounding, $100\ p_c$, $E_g = (1 + p_c) E_m$ (9)

The required full load series field ampere turns for flat or any desired compounding can be determined for any of the three cases shown in Figs. 1, 2, 3 and 4 by the following simple construction*. Fig. 5 represents the magnetization curve of the two machines composing the set, Ni_{sh} represents the shunt ampere turns and ϕ_1 the running light flux: a represents the equivalent negative ampere turns due to distortion, neutral setting of brushes assumed. If brushes are shifted from neutral, direct reaction must be taken into account.

From equations (4) and (6), speeds R are calculated with full load motor and generator induced e.m.f's. e_m and e_g, and for several values of ϕ_m and ϕ_g; the ampere turns Ni_m, Ni_{m2} etc., and Ni_g, Ni_{g2} etc., corresponding to each value of ϕ_m and of ϕ_g being taken from the magnetization curve Fig. (5).

Then the series ampere turns per circuit of generator,

$$Ni_{sg} = \left[Ni_g + a_g\right] - Ni_{sh} \qquad (10$$

and of motor, $$Ni_{sm} = \left[Ni_{sh} - \left[Ni_m + a_m\right]\right] \qquad (11)$$

The values of series ampere turns so obtained plotted against speed are, for flat compounding, shown in full line curve of Fig.(6). The point of intersection of motor and generator curves gives full load speed and series ampere turns for equal series ampere turns in motor and generator, i.e., series fields connected in the neutral (See Fig. 4); the intercepts with the horizontal above the intersection of the curves, in the proportion of motor to generator current, for the series fields connected each in series

* A similar though somewhat less direct determination of one case, the series fields connected in the neutral, is given in Mr. Frankenfield's paper above mentioned.

with its own armature (See Fig.1); and similar intercept below the horizontal, for series fields crossed over (See Figs. 2 & 3). For flat compounding the full load performance is obviously independent of shunt field connections. The influence which series field connections exercise upon stability of operation under varying load, particularly when subject to heavy overloads, is further suggested by the speed load curves shown in Fig. (7). Ordinates represent percent increase in speed above no load speed, and abscissas, the neutral amperes in percent of rated full load current. Curves A, B, and C show respectively the speed characteristics with series fields ~~cr~~ crossed, connected in the neutral wire and connected straight. Performances here given may be taken as fairly representative of balancers of from 300 to 500 amperes neutral capacity.

From equations (4) and (6)

$$e_g = e_m \frac{\phi_g}{\phi_m} \qquad (12)$$

or

$$E_g + \left[I_g (r_a + r_s -) + e_{bg} \right] = \left\{ E_m - \left[I_m (r_a + r_s) + e_{bm} \right] \right\} \frac{\phi_g}{\phi_m}$$

Combining with equation (7), $E_m = E - E_g$ and solving consecutively for E_g and E_m

$$E_g = \frac{E}{1 + \frac{\phi_m}{\phi_g}} - \frac{\left[I_g (r_a + r_s) + e_{bg} \right]}{1 + \frac{\phi_g}{\phi_m}} - \frac{\left[I_m (r_a + r_s) + e_{bm} \right]}{1 + \frac{\phi_m}{\phi_g}} \qquad (13)$$

$$\text{and } E_m = \frac{E}{1 + \frac{\phi_g}{\phi_m}} + \frac{\left[I_g (r_a + r_s) + e_{bg} \right]}{1 + \frac{\phi_g}{\phi_m}} + \frac{\left[I_m (r_a + r_s) + e_{bm} \right]}{1 + \frac{\phi_m}{\phi_g}} \qquad (14)$$

From equations (13) (14) and (3) or (5) together saturation and compounding curves Figs. 5 and 6, voltage division and speed can be estimated for any load.

With shunt fields crossed the inequalities in voltage division at loads between no load and full load, exact adjustment at those two points assumed, are practically negligible in sets of moderate or large capacity; with shunt fields connected straight and tapped to neutral the variation of voltage curves from straight line is usually very slight. In Fig.(8) is indicated clearly the general character of the voltage regulation curve and the amount of variation from the straight line which might be obtained in a very small set. The calculated and test results for a 400 ampere balancer over same load range showed no measurable departure from the straight line.

Division of current between motor and generator.

Let L_m, L_g = Losses (Except shunt field) of motor, generator.

W_m, W_g = Motor & Generator friction (journal & brush), windage, and iron losses including load losses.

With full unbalanced load,

$$I_n = I_m + I_g \qquad (15)$$

With no unbalanced load, $I_n = o$

$$I_m = -I_g = I_1 \qquad (16)$$

Since motor and generator are operating as separately exciter machines, the motor out-put equals practically the generator armature in-put or,

$$E_m I_m - L_m = E_g I_g + L_g$$

where $L_m = I_m^2 (r_a + r_s) + I_m e_{bm} + W_m$

$L_g = I_g^2 (r_a + r_s) + I_g e_{bg} + W_g$

$I_m = \frac{E_g}{E_m} I_g + \frac{L_m + L_g}{E_m}$

$= I_n - I_g$

$$I_g = \frac{\frac{I_n}{2} - \frac{L_m + L_g}{E}}{1 + \frac{E_g}{E_m}} \qquad (17)$$

$$I_m = \frac{\frac{I_n}{2} + \frac{L_m + L_g}{E}}{1 + \frac{E_m}{E_g}} \qquad (18)$$

This becomes for flat compound

$$I_g = \frac{I_n}{2} - \frac{L_m + L_g}{E} \qquad (17)$$

$$I_m = \frac{I_n}{2} + \frac{L_m + L_g}{E} \qquad (18)$$

and for over-compounding, $\frac{E_g}{E_m} = 1 + pc$

$$I_g = \frac{I_n}{2 + pc} - \frac{L_m + L_g}{E} \qquad (17)'$$

$$I_m = I_n \frac{1 + pc}{2 + pc} + \frac{L_m + L_g}{E} \qquad (18)'$$

Where motor and generator efficiencies are available, the following approximate equations for flat compounding are sometimes used:-

$$I_g = I_n \frac{\mathcal{E}_m \mathcal{E}_g}{1 + \mathcal{E}_m \mathcal{E}_g} \qquad (19)\ \dagger$$

$$I_m = I_n \frac{1}{1 + \mathcal{E}_m \mathcal{E}_g} \qquad (20)\ \dagger$$

† D. C. Balancers and compounding Frankenfield.

The value of I_g from (19) is slightly smaller than from (17') and I_m from (20) slightly larger than from (18)'.

For example in a balancer set of 200 amp. capacity, with normal full load efficiency, the division of current between motor and generator was found to be:-

From (17)' ' (18)'	I_m = 113 amperes	56-1/2% of neutral.	
	I_g = 87 "	43-1/2% " "	
From eq (19)&(20)	I_m = 115.3 "	57.6% " "	
	I_g = 84.8 "	42.4% " "	

Values by equations (19) and (20) are about two percent high in motor and low in generator current for full load in moderate sized sets: for partial loads the percentage inaccuracy is greater than on full load. For large sets, the full load values of current division check more closely, within about 1%; for small sets the difference is as much as 4%.

The current division, in percent of neutral current, will average about 42 percent generator, 58% motor; in very large sets, it may run ~~as low as~~ to about 47% generator and 53% motor, while in very small sets, 38% generator and 62% motor.

Efficiency of balancer sets.

Efficiency as motor generator set, $\mathcal{E}_B = \dfrac{\text{Set output}}{\text{Set input}}$

$$= \frac{E_g I_g}{E_m I_m + E_{shm} I_{shm} + E_{shg} I_{shg}} \qquad (22)$$

With close approximation, $\mathcal{E}_B = \mathcal{E}_m \mathcal{E}_g \qquad (23)$

For flat compounding at full load and approximately at other loads, from (22) $\eta_B = \frac{I_g}{I_m + 2I_{sh}}$ (24)

For over-compound, (1+pc) equation (22) becomes

$$\eta_B = \frac{(1+pc)\, I_g}{I_m + (2+pc)\, I_{sh}} \quad \text{---(24)'}$$

when the shunt fields are in series across the outers, and practically for other shunt field connections.

Obviously the motor generator efficiency of the balancer set gives an unfair, or at least an incomplete statement of the economy with which such equipments handle the unbalanced load. It has been proposed that the balancer efficiency be expressed in terms of unbalanced power delivered to the external circuit, $E_g I_n$, and the increase in power demand upon the main generator or plant, $E (I_m + I_{sh})$ i.e.,

$$\eta'_B = \frac{E_g I_n}{E (I_m + I_{sh})} \quad (25)$$

In this equation a constant term, $E_g I_m$, of in-transformed energy has been added to both numerator and denominator of the fraction (Fig. 24) expressing the ratio of energy transformation in the set. This hardly conforms to recognized conceptions of efficiency.

In order to give proper weight to balancer losses, the set should be considered in connection with the main generator, plant or feeding system of which it forms a part. An obvious objection to such procedure lies in the necessity for arbitrary assumption as to relation between generator and balancer loading

with varying total output. The simplest and probably best basis for estimate of performance is that of main generator and balancer both operating at full rated load. In general if,

I_o= current in mains due to apparatus operating across the outers.

I = current of half voltage apparatus in lighter loaded main.

I_n = Unbalance current in the neutral wire.

I_m , I_g, I_{sh}= motor, generator and shunt field currents of balancer.

then $I_o + I + I_m + I_{sh}$= output current of generator with balancer- assumed full load.

Kw_I= Full load input of generator.

L_B = Total losses in balancers at full load.

See Fig. 9

Efficiency of generator alone, $\mathcal{E}_{MG} = \frac{E\,(I_o + I + I_m + I_{sh})}{Kw_I}$ (26)

Combined efficiency of generator and balancer $\mathcal{E}_{MGB} = \frac{E(I_o+I)+I_n E_n}{Kw_I}$ (27)

For flat compound (27) becomes $\frac{E\,(I_o + I + \frac{I_n}{2})}{Kw_I}$

which combined with (26), $\mathcal{E}_{MGB} = \dfrac{1}{1 + \dfrac{I_B}{E(I_o + I + \frac{I_n}{2})}}\ \mathcal{E}_{MB}$ (28)

With all apparatus operating at one half the voltage between outers, $I_o = 0$, Equation (28) reduces to $\mathcal{E}_{MGB} = \dfrac{1}{1 + \dfrac{I_B}{E(I + \frac{I_n}{2})}}\ \mathcal{E}_{MB}$ (28)'

For example consider a 250 K.W., 250 Volt generator installed with a balancer to take care of 20% unbalance current in the neutral, a 200 amp. 250/125 Volt set being required, $I_o = 0$.

Assume 92% full load efficiency of generator.

$I_m = 113$ $I_{sh} = 2.3$ amps.

$I_B = 3800$ watts.

$I + I_m + I_{sh} = 1000$ amps.

$I = 884.7$ amps.

Then on full load, $\mathcal{E}_{MGB} = \dfrac{92.0}{1 + \dfrac{3300}{250(884.7 + 100)}} = 90.6\%$, the plant efficiency being lowered 1.52 per cent by use of balancer.

On partial loads, even assuming that the balancer load decreased in proportion to main load, the effect upon plant efficiency would be more marked.

In large plants where the percentage of unbalanced load is small, the balancer losses lower only slightly the plant efficiency; while for very small plants, the influence of such losse is more marked than suggested above.

* If $I_o = 400$ amperes, a 120 amp. balancer would be required for the same total generator output, and the plant efficiency assuming balancer losses of about 2600 watts becomes 91.25%, a loss in efficiency of only .9 percent due to balancer.

Commutation:-

Since the units composing a balancer set act alternately as motor and generator, the brushes must be set on or near the no load neutral position; advantage can be taken of the commutating fringe from the main pole only in a limited way,* and reliance must be placed largely upon "forced" commutation. Machines designed or selected for such service should have excellent commutating characteristics, or else be proportionately under-rated.

Choice of constants and of machine proportions leading to low reactance voltage, a small value of armature flux and a flat main field in the interpolar space tend to insure good commutation. High resistance brushes are in the main, desirable.

In general where N_{tl} = number of turns per armature coil

l = Length of armature in inches.

v = Peripheral velocity of armature in ft. per sec.

Δ = Peripheral current density of armature in amperes per inch of armature circumference,

the permissible value of the armature constant, $N_{tl}\, l\, v\Delta.10^{-8}$ varies between 0.12×10^{-2} and 0.2×10^{-2}. The reactance voltage per coil, e should preferably be kept within the limits of to , and the short circuit voltage between brush tips, $l_{RB.}$, of to . In such equipments, since commutation rather than heating is usually the limiting factor in design, auxiliary commutating fluxes can be employed to advantage. a set made up of two interpole machines being in general smaller and cheaper per K.W. than the non interpole.

* Brushes may be given a slight shift against rotation, giving to the motor, which carries the heavier armature current and has the weaker main field, a slight advantage in position.

Stability & Compounding:

Stable operation of compound wound balancer sets, even where subject to sudden and heavy overloads, is obtainable if the units making up the set are designed for this service, and the proper field connections used. In general, the most stable performance results where there is least change in quantity and distribution of motor field flux for the maintenance of balanced voltage with varying load. A low value of the armature and series field resistance, requiring relatively small differential action in the motor fields and a small working range on the magnetication curve with slight departure from the straight line, are favorable. It is obviously desirable that the series fields be crossed, so that compounding takes place with minimum speed increase. (See Fig. 6). The armature distorting ampere turns per pole, $1/2\Delta l_p$, should be kept low; or, more strictly, the ratio of the ampere turns per circuit for air gap and teeth, Ni_{gt}, to the distorting ampere turns per circuit, Δl_p should be sufficiently large, in general $\frac{Ni_{gt}}{\Delta l_p} \geq 1.1 \text{ to } 1.3$ The effect of armature distortion upon speed is suggested by a comparison of the dash and full line curves of Fig. 6: in the former, the weakening of the main field due to armature distortion is neglected, while in the latter this factor is taken into account. The speed increase in this case chargeable to distortion is about 2 per cent.

Though balancers are ordinarily wound for flat compounding, yet where the set must be located at a considerable distance from the feeding point, over-compounding to compensate for feeder drop is desirable. The degree of over-compounding available is limited by the stability of the set on overloads such as occur under service conditions. Reasonable over-compounding, about 5 percent, is readily obtainable in conservatively designed sets.

Parallel Operation:

Compound wound balancers will operate satisfactorily in parallel, if proper interconnections are provided. Two sets either identical or having like compounding characteristics will divide load proportionately when running in parallel if supplied with equalizer connections between armatures, one connection being required if the series fields are in the circuit of the neutral wire (Fig.10), two if the series fields are in the circuits of armatures of the individual machines (Fig.11). Balancer sets with dissimilar compounding characteristics can be made to operate in parallel with proper load division, if provided, in addition to equalizing connections, with auxiliary resistances, r_{sx}, to be connected in series with the series fields of one set. (Fig. 12) and of such value that when each set is carrying its rated proportion of the total unbalanced load, the voltage drop between armature terminals and neutral wire shall be the same in both sets, i.e., I_m, $r_s = I_{m2}(r_{s2} + r_{sx2})$ and I_g, $r_s = I_{g2}(r_{s2} + r_{sx2})$.

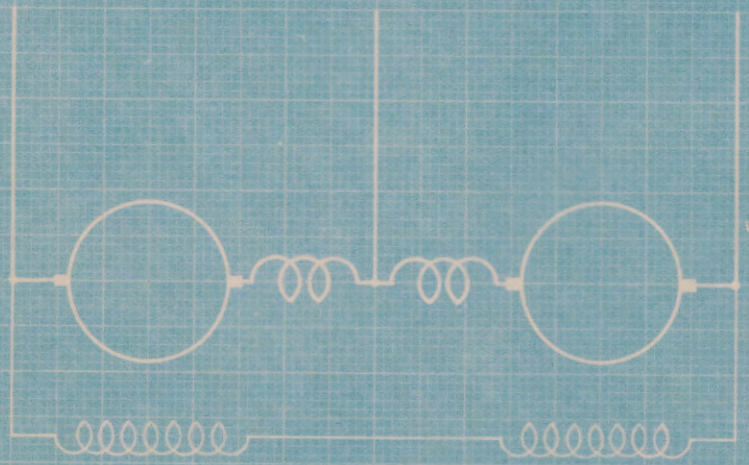


FIG. 1.

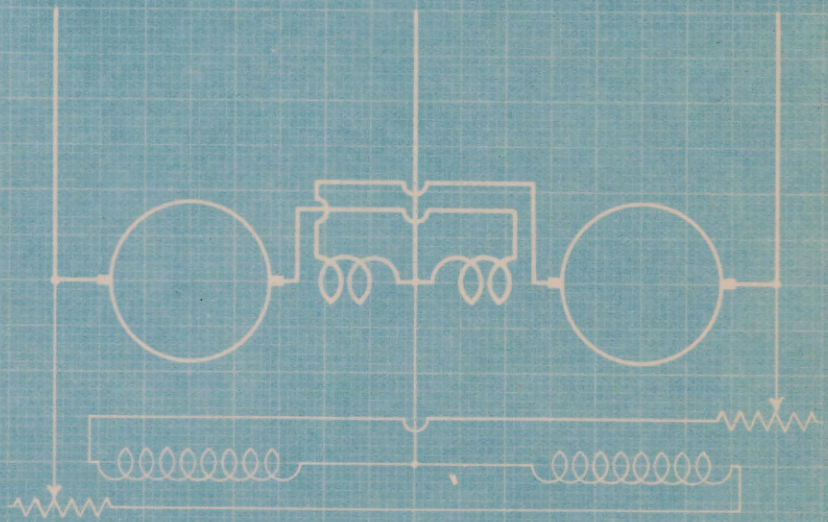


FIG. 2.

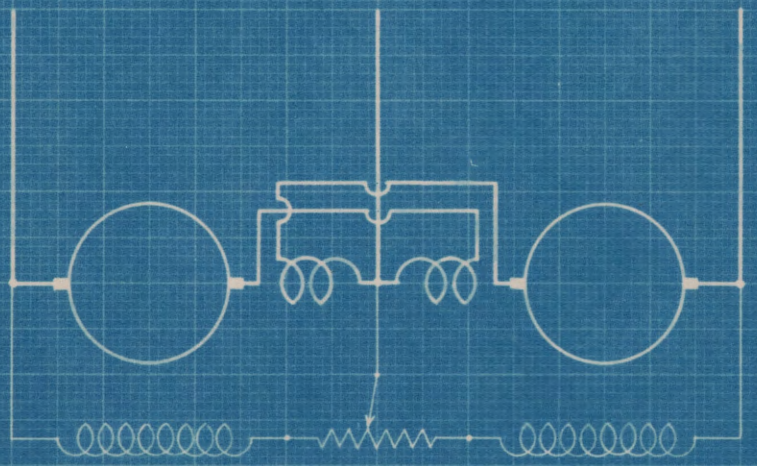


FIG. 3.

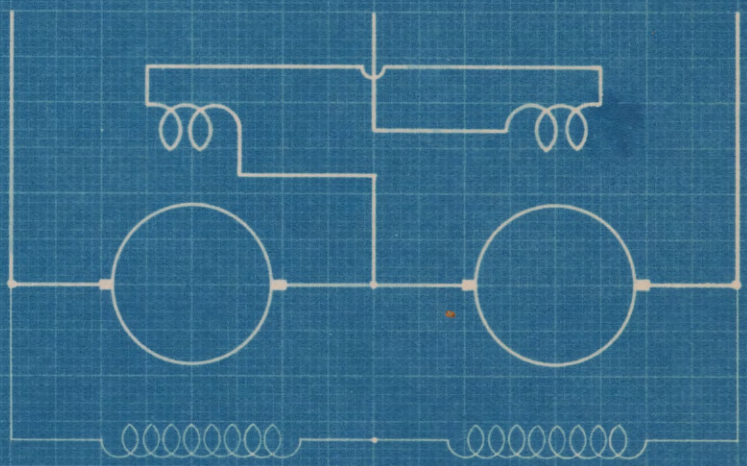


FIG. 4.

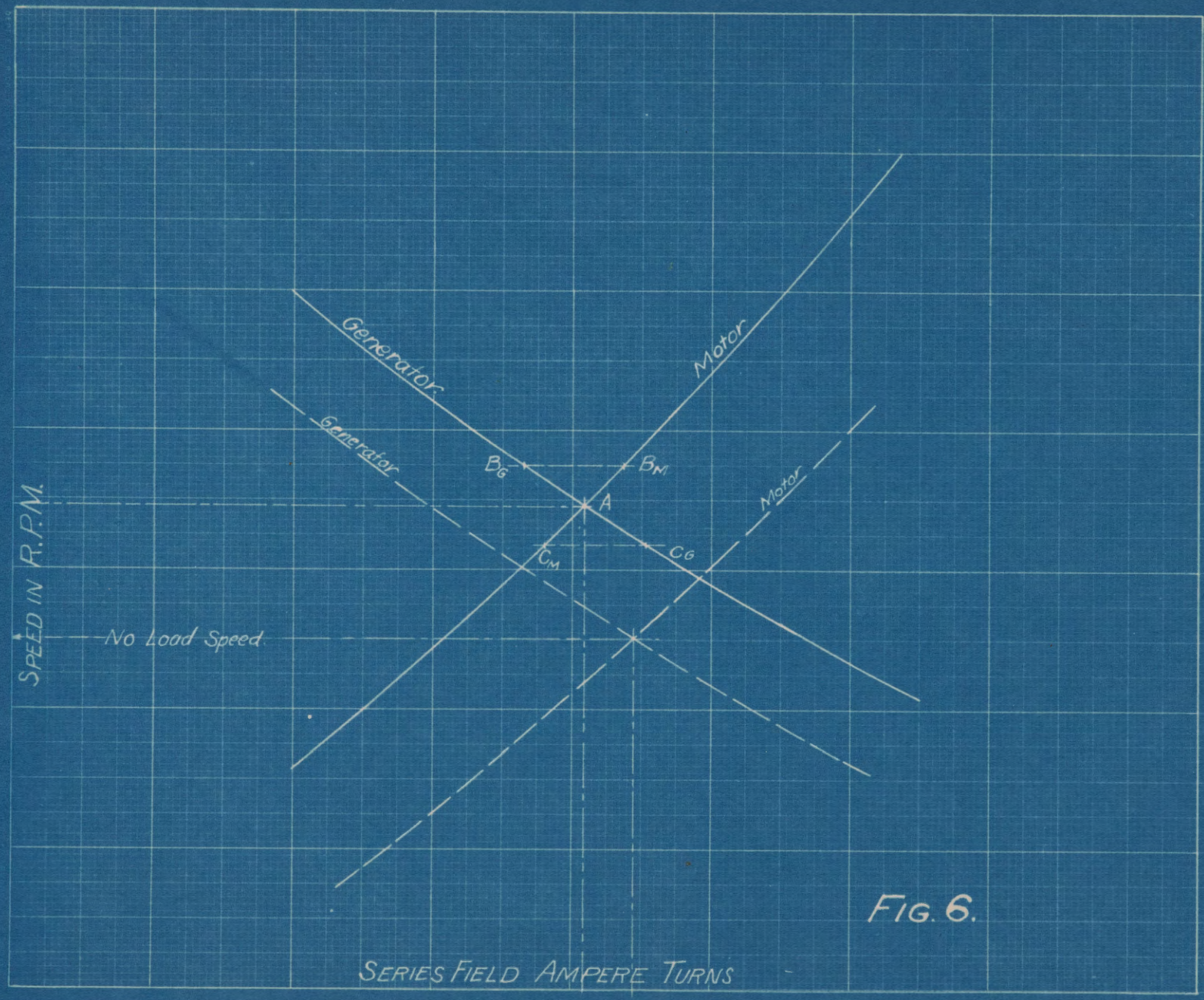

Generator
Motor
Generator
Motor
B_G
B_M
A
C_M
C_G
No Load Speed
SPEED IN R.P.M.
SERIES FIELD AMPERE TURNS

FIG. 6.

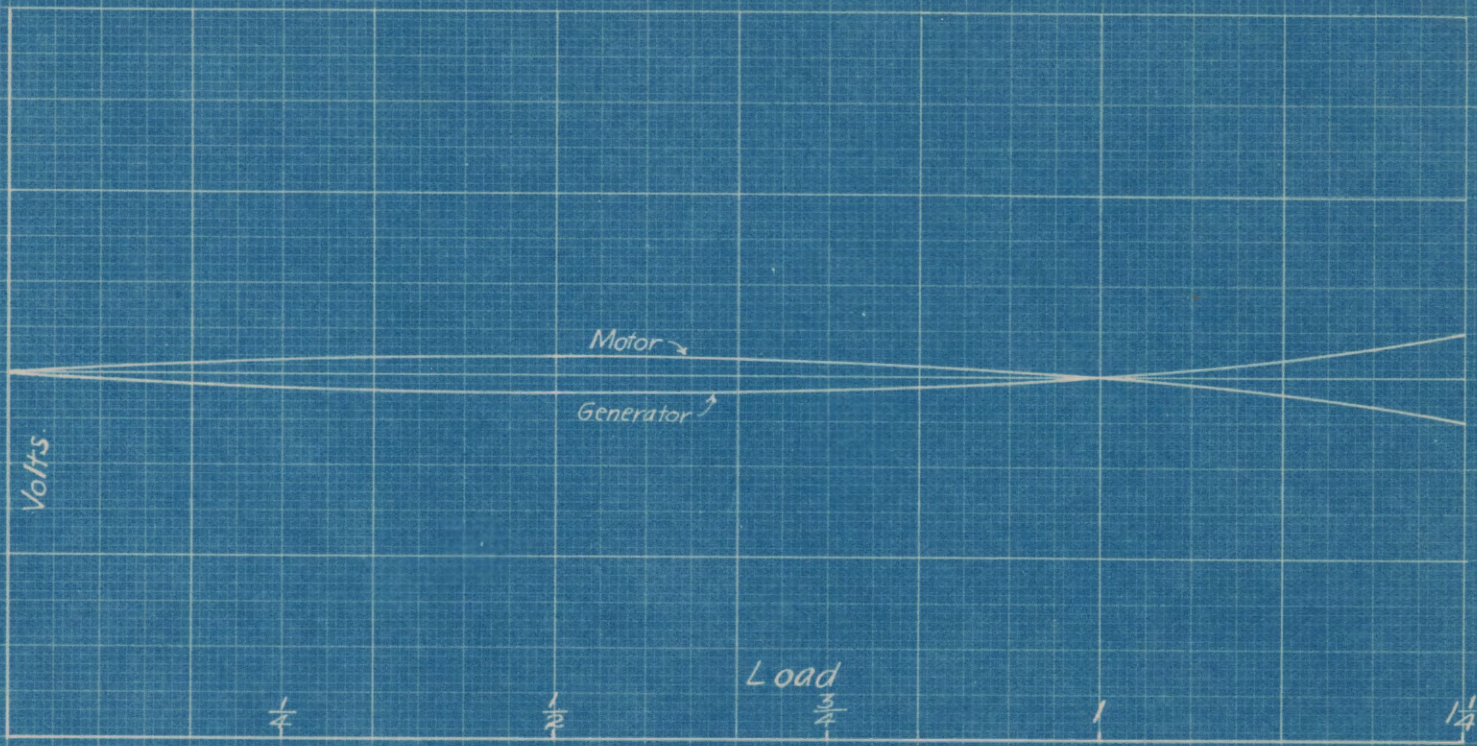


FIG. 8.

THESIS.

TESTS ON THREE GENERAL ELECTRIC TRANSFORMERS.

BY ALEX. C. LANIER, B.S. in E.E. 1900.

THESIS IN ELECTRICAL ENGINEERING.

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TESTS ON THREE GENERAL ELECTRIC TRANSFORMERS.

--- In the electric transformation of power, transformer economy is an important factor. Especially is this the case in lighting circuits, where the transformer is on open circuit for eighteen hours out of every twenty four, the power consumed during this time being an absolute loss.

Previous to the year 1895, the only sets of tests of any importance were those made on only a few transformers by Prof.H.J. Ryan, and published in 1889, and the more comprehensive set made by Mr.Flemming in 1892. The latter determined experimentally the most accurate method for transformer testing, and tested a great number of converters of different makers, and of varying sizes. The losses were determined by measuring the in-put and out-put of each machine, and so did not admit of seperation.

In 1895 Mr.Arthur Hilyer Ford made a number of experiments upon different sizes and makes of transformers, in which he determined the copper and iron losses seperately, thus making it possible to judge transformers, not only by their full load efficiencies but by thepractical all day running efficiency, which two quantities may vary widely in different makes.

The following tests are not complete. Only three transformers of modern design could be obtained, and these all of the same maker,- the general Electric Company. The objects of the experiments may be briefly stated:-

I. To determine losses and efficiencies.

II. Magnetizing current and power factor on open ~~coil~~ circuit.

III. Regulation -- to determine drop in secondary pressure as transformer is loaded up.

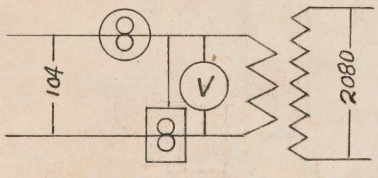
IV. Heating on open circuit and fully loaded.

Besides these it was hoped to work out some problems regrding the all day efficiencies of transformers under conditions of operation on some of the lines of the City Light & Power Company.

METHODS OF TESTING.-- There are various methods used in testing transformers, but the Wattmeter methods are now accepted as the most reliable.

The efficiency determinations were made by what is called the stray power method, i.e., the iron and copper losses were found seperately by experiment, from which the efficiencies were calculated from the formulae $E. = \frac{W.}{W. + L.}$; where W. = any assumed secondary out-put, and L.= the loss for that load.

IRON LOSSES. -- The method here used is that of Dr.Sumpter; the connections are explained in the following drawing. The low



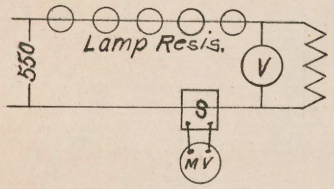
pressure coil of the transformer to be tested is connected in a circuit of of voltage equal to that which the low pressure terminals of the transformer are designed to give. In this circuit is placed a wattmeter and an ammeter, and across it is connected a voltmeter. The reading of the wattmeter when the high pressure coil is on open circuit will give the iron loss at that voltage. Ammeter and voltmeter readings will give data from which to cal-

culate power factor on open circuit, from the formula W.= EC cos.ϕ, where W., is reading of wattmeter, and E.& C., the volt and ammeter and cos.ϕ, the power factor.

The magnatizing current is equal to the ammeter reading, divide by K, the ratio of transformer. The C^2R. loss under the above conditions is negligible, amounting to about .04 % of total wattmeter reading.

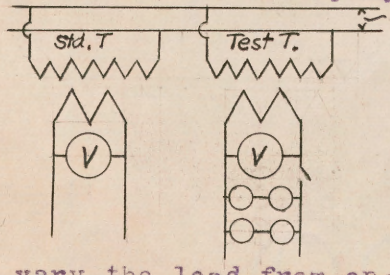
Iron losses were computed both cold and hot. Hot losses were taken ~~before~~ after heating test, both on open circuits and fully loaded.

COPPER LOSSES. -- These were calculated for different loads after having measured the primary and secondary resistances. These resistances were measured by the fall of pressure method; connections are shown in the accompanying cut. The current flowing



through the coils was read from the shunted mille voltmeter, reading up to two amperes, the voltage drop was read by a Western voltmeter for primary coils, by a mille-voltmeter in series with a 100 to 1 multiplier for the secondaries. The resistance was then calculated from Ohm's Law -- $R. = \frac{E.}{C.}$

REGULATION. -- The tests for regulation were made, as shown in the accompanying cut, by connecting two transformers across the high



pressure circuit. Across the secondary terminals of each a voltmeter is connected. The transformer has in its secondary circuit a bank of lamps, which can be made to vary the load from open circuit to one half over-load. The other transformer is kept on open circuit. Simultaneous readings of

the two machines for increasing loads on the one to be tested, are taken. The differences of these readings will give the pressure drop for each load.

HEATING. -- The transformers were operated for six hours both on open circuit, and fully loaded. The heating of the air space between the transformer and the casing was taken with a Centigrade thermometer, the bulb of which was wrapped in waste. The heating of the coils, which may be taken as approximately that core, was obtained by measuring the hot resistance of the primary coil. If $R._a$ stands for resistance at temperature a. $R._b$ the resistance at temperature "b" and α the temperature co-efficient, then the equation

$$R._a = R_b(1 + \alpha(a - b.))$$ gives the relation between the resistances and temperatures.

SOURCES OF CURRENT. -- The transformers for heating and regulation tests were operated on the 2080 Volt alternating current, lighting circuit of the City Lighting Company. For iron loss measurments the 104 Volt secondary circuit from the same source was used. The frequency is 133 periods per second. For resistance measurements the 550 volt direct durrent of the Street Railroad was used. All of these sources were very conveniently arranged in the testing room of the Knoxville Light, Power & Traction Company. In all, the voltage was very unsteady. During the day ~~time~~, the alternators are run from the same shaft, as the Railroad generators. The shaft speed of course varies with the load upon it.

The instruments used in these experiments were;

Weston alternating current Wattmeter, reading from 0 to 150 Watts.

Cardew Voltmeter, reading from about 30 to 120 Volts.

Thompson's Alternating Current Voltmeter, reading from 0 to 125 Volts.

Queen Electro-dynamometer, reading from 0 to 5 Amperes on the light coil, and from 0 to 20 amperes on the heavy coil.

Thompson Alternating Current Ammeter, reading from 0. to 25 Amperes.

Weston Direct Current Mille-Voltmeter, reading from 0. to 20 mille-volts; with its 100 to 1 multiplier from 0 to 2, volts; With its shunt reading from 0 to 2, 20, and 200 Amperes.

Weston Direct Current Voltmeter No. reading from 0 to 15, and 0 to 100 Volts.

The Weston Voltmeter read low by two of the small scale divisions.

CALIBERATION OF INSTRUMENTS. -- The ThompsonAlternating Current Voltmeter and Cardew Voltmeter were caliberated on direct current ~~with~~ using Weston Voltmeter as standard. The following table gives readings of each, and correction to be made for each reading.

D I R E C T C U R R E N T .

WESTON Vm. I Standard.	Readings.	Corect.	CARDEW Vm. I Readings.	Correct.	THOMPSON ALT.Vm. I Readings.	ELECTROSTATIC V
34.	34.5	-.5	31.5	+2.5	----	
49.5	51.	-1.5	48.5	+1	50.*	
58.5	59.5	-1.	57.5	+1	58.*	
65.5	65.	+.5	62.5	+3	64.5	
73.	72.	+1.	69.5	+3.5	71.6	
80.	79.	+1.	82.	-2.	80.	
88.5	88.5	---	88.5	+3.	88.5	
105.	105.5	-.5	103.	+2.	104.	
110.	111.5	-1.5	108.	+2.	109.3	
Average Correction,	-.3 Nearly			+1.8 Short.		

* These readings were only approximate.

O N A L T E R N A T I N G C U R R E N T. f. = 133.

CARDEW Vm. Readings.	Corrected.	I THOMPSON ALTERNATING CUR.Vm. Readings.	Correction.
108.	107.7	110.	-2.3
105.	104.7	107.	-2.3
103.5	103.2	106.	-2.8
103.	102.7	105.	-2.3
106.	105.7	108.	-2.3
105.	104.7	106.	-1.3
103.	102.7	103.	-.3
102.	101.7	103.	-1.3
99.	98.7	101.	-2.3

Average Correct. -2. Nearly.

* The corrected Cardew Reading is taken as Standard.

~~Plate 1. shows curves of caliberation; Curve 1. and 2. give readings of Cardew and Thompson Alternating Current Voltmeter, taken in direct current circuit. Curve 3. is comparison of Thompson Alternating Current Voltmeter and~~

AMMETER ON ALTERNATING CIRCUIT. f.= 133

ELECTRO-DYNAMOMETER.	I	THOMP.ALT.CURRENT AMMETER.	
Readings.	Amperes.	Readings.	Correction.
203.5	3.1	2.*	+1.1
20	5.4	5.7	-.3
33.2	7.	7.2	-.2
51.5	8.7	8.6	+.1
74.	10.4	10.1	+.3
114.	12.9	12.5	+.4
171.	15.8	15.1	+.7
259	19.4	18.2	+1.2
376.	23.5	21.1	+2.4

**The reading on this part of the ammeter scale was largely approximate.

The first reading of the electrodynamometer was taken on the light coil, - all the others on the heavy.

The electro-dynamometer, using constant of $0.217\sqrt{\text{reading}}$ for light coil, and $1.21\sqrt{\text{reading}}$ (as determined by writer)* for the heavy coil, is assumed as standard in caliberation of the Thompson Alternating Current Ammeter. The wattmeter was a Weston low reading Wattmeter and was assumed to be correct.

Plate 1. shows curves of caliberation. Curves 1. and 2. give readings of Cardew and Thompson Alternating Current Voltmeters on direct current circuit. Curve 3. gives comparison of Thompson Alternating Current Voltmeter with Corrected Cardew readings, assumed as true volts.

Curve 4. compares readings of the Thompson Alternating Current Ammeter with the Queen Electro-dynamometer, as a standard.

The record of laboratory measurements for each test are made, and following these are the deductions and calculations made from the experiments. Curves of efficiency and copper loss are found on plates 2. and 3. of regulation on plate appended to this thesis.

For brevity, the 1500 Watt General Electric Transformer will be called No.1. , The 2500 Watt Transformer No.2. and The 5000 Watt Transformer No.3.

* By comparison with shunted Mille Voltmeter.

TRANSFORMER NO .1.

Iron Losses -- Cold.

WattMeter.	Volt.Alt.Vm.	Elec'ym.	Reduced Rdgs. ~~Equiv.~~
33.	102.	7.25	.586

RESISTANCE, SECONDARY WINDINGS.

Shunted M.Vm. 0 to 2.	Amperes Equiv.	M.Vm.Mult.	Volts.	R.=E/C.
9.2	.92	.4	.04	.043
9.4	.94	.4	.04	.042

Average R. = .0425

PRIMARY RESISTANCE.....

Shunted M.Vm. I	Amperes.I	Voltmeter. I	R.=E/C.
8.4	.84	38.	95.24
8.8	.88	39.	44.32
8.	.8	36.	45.
8.	.8	36.	45.

Average Resistance=44.9

TRANSFORMER NO. 2.

Iron Losses -- Cold.

Wattmeter.	Thonp.Vm.	Electrod.	Reduced Rdgs.
40.	102.	8.5	.629

AFTER RUNNING ~~SIX~~ 7.5 HOURS ON NO LOAD.

Wattm.	Thomp.Alt.Vm.	Elecdy.	Reduced Rdgs.
37.	100.	9.	.651

AFTER SIX HOURS RUN ON FULLLOAD.

Wattmeter.	Thomp.Alt.Mv.	Elecdy.	Reduced Read'gs.
36.	100.	9.5	.668

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SECONDARY RESISTANCE..

Shunted M.Vm.	Amperes.	M.Vm.Multp.	Volts.	R.= E./C.
8.8	.88	2.5	.025	.0284
9.	.9	3.	.03	.0333
9.	.9	2.5	.025	.0278

Average Resistance.= .03

PRIMARY RESISTANCE --- TEMP. 21.5

M.Vm. Shunt.	Equiv.Amp.	Voltm.	Corrected Vm.	R.= E./C.
8.3	.83	17.	19.	22.9
8.3	.83	17.	19.	22.9
8.8	.88	18.	20.	22.7

Average R. = 22.8

PRIMARY RESISTANCE AFTER 6½ HOURS RUN ON OPEN CIRCUIT.

M.Vm.+Shunt.	Equiv.A.	Volym.	Corrected Vm.	R.= E./C.
9.	.9	20.	22.	24.4
9.3	.93	21.	23.	24.7
8.6	.86	19.	21.	24.4

Average Resistance = 24.5

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PRIMARY RESISTANCE AFTER 6 HOURS RUN ON FULL LOAD.

PRIMARY RESISTANCE AFTER SIX HOURS RUNON FULL LOAD.

M.Vm.+Shunt.	Equiv.A.	Volym.	Corrected Vm.	$R.=\frac{E.}{C.}$
9.4	.94	23.	25.	26.6
9.7	.97	24.	26.	26.8
9.7	.97	23.	25.	25.9
9.2	.92	22.	24.	26.1

Average Resistance 26.3

T R A N S F O R M E R N O . 3.

Iron Losses -- Cold.

Wattm.	Electrdym.	Amperes.	Voltmeter.
73.	25.	1.085	100.

IronLoss After 6½ Hours Run on Open Circuit.

WattM.	Elecdyn.	Amperes.	Voltmeter.
71.	25.5	1.096	100.
68.	25.	1.085	98.

IRON LOSS AFTER 6 HOURS RUNON FULL LOAD.

Wattm.	Elecdyn.	Amperes.	Voltmeter.
71.	26.	1.107	99.
71.5	27.	1.128	99.
66.	23.	1.042	97.

SECONDARY RESISTANCE.

Shunt.M.Vm.	Amperes.	M.Vm.	Volts.	R.= E./C.
10.	1.	12.6	.0126	.0126
9.6	.96	12.nearly	.012	.o125

PRIMARY RESISTANCE.-- TEMP. 21.7

Shunt.M.Vm.	Amperes.	Voltm.	Cor.Vm.	R.= E./C.
8.4	.84	8.5	10.5	12.5
8.	.8	8.15	10.15	12.69
8.8	.88	8.9	10.9	12.39

Average 12.5 Ohms.

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PRIMARY RESISTANCE HOURS RUN OPEN CIRCUIT.

Shunt.M.Vm.	Amperes.	Voltm.	Corfected Vm.	R.= E./C.
9.8	.98	10.5	12.5	12.75
10.1	1.01	11.	13.	12.87
9.6	.96	10.4	12.4	12.91

Average Resistance = 12.8

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PRIMARY RESISTANCE SIX HOURS RUN FULL LOAD.

(Over)

Shunted M.Vm.	Ampres.	Voltm.	Corrected Vm.	R.= E./C.
10.	1.0	11.1	13.1	13.1
9.	.9	11.	13.	14.8
8.4	.84	10/7	12.7	15.1
9.	.9	11.	13.	14.8

Average 14.5 Ohms.

REGULATION TESTS.....

The standard transformer registers its voltage on the Thompson Alt.Vm. in each instance, the one to be tested onthe Cardew. Several readings were made at each load. Transformers were tested for open ~~current~~ circuit up to one-half over-load.

TRANSFORMER NO. 1/.

Stand'd. Trans.	Trans.No.1.	Load.
THOMP/	CARDEW Vm.	AMPS.
109.	110.	(Open Cir.)
110.	108.	6.5
109.	105.	10.
110.	105.	"
111.	107.	"
112.	108.	10.2
110.	105.	16.7
109.	105.	16.5
112.	105.4	16.6

(Over)

109.	104.	19.8
108.	102.	19.7
108.	103.	19.8
109.	103.	"

TRANSFORMER NO.2.

Std.Transformer.	Trans.No.2.	Load Amp.
112.	110.	Open C.
117.	105.	" "
111.	110.	" "
109.	106.	8.3
108.	105.	"
110.	107.	"
109.	105.2	17.3
110.	106.	17.4
111.	107.	17.3
108.	103.	23.
110.	105.	23.2
110.5	105.4	23.
109.	103.	10+
111.	105.	10.1+
110.2	104.	10.2+

* The ammeter was shunted with copper wire, the reading reduced from 23.2 to 6.7. Load = 3.46 X Reading. Cardew Vm. at. 5.3 Vs.at start.

TRANSFORMER NO. 3.

Stand. Transf.	Transformer No. 3.	Load Amp.
110.	114.	Open Circuit.
109.	113.	"
110.	113.	11.2
110.	114.	11.3
109.	113.	21.7
109.	113.	21.8
110.	113.	8.1*
110.	113.	8.1
109.	111.5	10.
110.	112.5	10.
111.	112.	11.9
110.	112.	"
111.	112.5	"
110.	111.6	13.9
111.	112.	13.9
109.	110.5	14.

* Ammeter shunted from 21.7 to 6 or Load = 3.6 X Reading.

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TABULATION OF RESULTS.

In the following tabulations all readings have been corrected to true volts, amperes, or watts, as the case may be.

LOSSES AND EFFICIENCIES. -- The primary and secondary

copper losses, and combined copper losses, and the efficiencies are calculated for 1/4, 1-2, 3-4, and full load, and 1-2 overload. There are three iron losses tabulated; Cold Losses, Those after ruuning on open circuit, and those after running on full load. The temperature given in each case is that of the primary coil. The iron losses are corrected to equivalent losses at 104 Volts. In this connection it was assumed that the iron loss varies as the 1.6 power of the electro-motive force, which is approximately true, since at frequency of 133 the eddy current loss is low. The current varies with the elector-motive force.

Where more than one measurement was made the average is taken. Transformer No.1. was removed before any heating tests could be made upon it, so that only cold losses and resistances could be gotten.

In the calculation of the all-day efficiencies it was assumed that the transformers ran on no load nineteen hours, and full load for five hours during the day.

TRANSFORMER NUMBER 1.

Iron Losses.

Wattmeter.	Excit. Amperes.	Volts.	Primary.	Temps.
~~35.2~~	.609	104.	44.9	---

Magnetizing current on 2080 Volt Circuit = .0304 Amps.

Power Factor on Open Circuit = .56 . f. = 133 ~~Copper Loss.~~

COPPER LOSSES.

PRIMARY C. Loss.	SECONDARY C. Loss.	COPPER L. Loss.	SECOND. AMPS.	EFF.
1.46	.55	2.01	3.6	91%
5.83	2.2	8.03	7.2	94.5
12.1	5.	17.1	10.8	95.5
23.32	8.81	32.13	14.4	95.7
52.47	19.83	72.3	21.6	95.4

Primary Resist. 44.9 Secondanry Res. .043

Maximum Efficiency 95.7 at Full Load.

All-efficiency --- 88.3 nearly.

TRANSFORMER NUMBER 2.

Iron Losses.

WattMeter.	Excit.Amps.	Volts.	Prim.Res.	Temps.
44.3	.654	104.	22.8	21.5°
41.7	.69	104.	24.5	60.°
40.5	.709	104.	26.3	76.°

Mag.Current on 2080 Volt Circuit = .0327 Amps.

Power Factor on Open Circuit = .65 f. = 133.

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Copper Losses.

Prim.C.Loss. Watts.	Sec.C.Loss. Watts.	Copper Loss. Watts.	Sec.Amps.	Eff.
1.93	1.07	3.00	6.	93.3
7.72	4.29	12.01	12.	95.8
17.37	9.66	27.03	18.	96.4
30.87	17.16	48.03	24.	96.5
69.47	38.61	108.08	36.	96.+

Primary Resistance = 22.8 Temp.= 21.5

Secondary Resistance = .03 Maximum Efficiency 96.5 at full Load. All Day Efficiency 90.5

TRANSFORMER NUMBER 3. -- Iron Losses.

Wattm.	Excit.Amps.	Volts.	Prim.Rest.	Temperature.
81.	1.15	104.	12.5	22.°
78.7	1.169	104.	12.8	50°
78.4	1.17	104.	14.5	77.°

Mag.Current on 2080 Volt Circuit(Cold) = .0575 Amps.

Power Factor on OpenCircuit = .686 f. = 133.

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Copper Losses.....

C^2R_p.Loss.Watts.	C^2R_s.Loss.Watts.	Total C^2r.Loss Watts.	Sec.Load. Watts.	Eff.
3.6	1.8	5.4	12.	93.5
14.2	7.2	21.4	24.	96.
32.	16.2	48.2	36.	96.5
56.9	28.8	85.7	48.	96.6
127.9	64.8	192.7	72.	96.1

Prim.Resist. -- 12.5 Temperature 21.7°

Secondary Resist. .0125 Max.Efficiency 96.6 at full Load.

All Day Efficiency -- 92%. Plate 2. gives curves of efficiency, copper and combined losses.

R E G U L A T I O N .

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The results of these tests are given in the following tables in which the symbols are used as follows. C_p, Cs, Rp, and Rs, for primary and secondary currents, and resistances. CRp. and CRs. for the primary and secondary drop in pressure due to resistances in their respective coils. V. the total pressure drop. Es.= the Secondary Volts corresponding to 2080 Primary.

The table contains, primary impressed pressure, calculated from corrected secondary pressures of the standard transformer, (from formulae $Ep.= \frac{n'}{n''} Es.$ where $\frac{n'}{n''}$ is assumed as 20); Secondary pressures corresponding to 2080 Volts primary; total pressure drop from corrected secondary pressures; CRp. and CRs., calculated from known resistances and loads; Leakage drop, which is the difference between the total drop and the added CR drops, or (V—CR.)

TRANSFORMER NUMBER 1.

Ep. Volts.	Es.# Volts.	V. Volts.	Crp. Volts.	Crs. Volts.	V-Cr. Volts.	Load. Amps.
2140.	104.	0	0	0	0	0
2160	101	3.	.67	.27	2.02	6.3
2200.	99.	5.	1.16	.44	3.4	10.3
2140.	98.	6.	1.93	.74	3.3	17.3
2120.	97.5	6.5	2.35	.9	3.25	21.

Primary Resistance -- 44.9 Secondary Resist. -- .043

Full Load Cs.= 14.4 Cp.=.72 V.= 5.57 CRp.= 1.6 CRs.= .62

Leakage Drop = 3.35 ..

* Secondary Volts corresponding to 2080 Primary.

TRANSFORMER NO. 2.

Ep. Volts.	Es. Volts.	V. volts.	CRp. Volts.	Crs. mVolts.	V.-CR. Volts.	Sec. Load.
2200.	104.	0.	0.	0.	0.	0.
2140.	103.	1.	.47	.25	.28	8.3
2180	102.	2.	.98	.52	.5	17.3
2120.	101.	3.	1.31	.69	1.	23.
2180.	100.	4.	2.	1.05	.95	35.

Primary Resistance -- 22/8 Temperature 21.5

Seconadry Resistance .03 Full Load, Cs.= 24 Amps.

Cp.= 1.2 V.= 3.1 Crp. = 1.37; CRs. = .72

Leakage Drop = 1 Volt.

TRANSFORMER NUMBER 3...

Ep§ Volts.	Es. Volts.	V. Volts.	CRp. Volts.	Crs. Volts.	V-CR. Volts.	Sec. Load.
2140.	104.					
2160.	103.5	.5	.35	.14	.01	11.2
2140.	104.	--	.68	.27	Neg.	21.7
2160.	103.	1.	.91	.37	Neg.	29.2
2140.	102.5	1.5	1.13	.45	Neg.	36.
2180.	101.5	2.5	1.34	.54	.62	42.8
2140.	101.3	2.7	1.57	.63	.5	50.4

Primary Resistance -- 12.5 Temperature 21.7

Secondary Resistance - .0125 Full Load --*

*Cs.= 48. Cp.= 2.4 V.= 2.6 CRp. = 1.5 CRs.=.60

Leakage Drop = .5 Plate 3. gives curves of total and of combined CR Drop..

HEATING TESTS. -- For the heating test the transformers were worked for about six hours, both on open circuit and fully loaded, as stated in the beginning. Transformers were kept in cases during both runs. No experiments were made on the heating when running in oil as was at first expected.

In the following tables only average values are given, and these cannot be depended upon, For this reason, no fractions of a degree are recorded, except in thermometer readings. The first line gives heating for open circuit,- the second for full load. Transformer No.1. was removed before the heating test could be made on it.

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TRANSFORMER.....NO.2...

Time -- Length of Run.	Temperature. Air.	Core.	Rise.	Rise from Prim.Resist.	Of Coil $t_a + r_a$	Load. Amps.
7 1-2	20.7	33.	12.3	39°	60°+	Open C.
6.	22.	44.5	22.5	55°	77°	25.

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TRANSFORMER NUMBER 3.....

Time. Duration of run --Hours.	Load. Amperes.	Temperatures/. Air.	Core.	Rise.	Rise from Prim.Resist.	Of Coil. $t_a + r_a$
6 1-2	Open C.	21.5	36.	14.5	28.	50/.
6.	50.	22.	54.	32.	55.	77.

SUMMATION OF RESULTS.

In the table given below, the attempt has been made to draw together such records of, or deductions from the preceeding experiments, as are of importance for a comparative view of the transformers. Losses, efficiencies, and regulation wherein they vary with the load are recorded below for full load. All figures have been corrected for 104 Volts, Secondary Voltage.

(For Table See Next Page.)

Number.	Output	Losses		Efficiencies		Magnetizing Current.	Power Factor at No Load.	Regulation.				Heating.	
		Iron	Copper	Max.	All-day			Total Drop	CR_p	CR_s	Leakage Drop	Open Ciruits	Full Load.
	Watts	Watts	Watts	%	%	Amps.	Cos ϕ	Volts	Volts	Volts	Volts	Deg. C	Deg. C.
1	1500	35.2	32.1	95.7	88.3	.03	.56	5.57	1.6	.62	3.35		
2	2500	44.3	48.	96.5	90.5	.033	.65	3.1	1.37	.72	1.	39	55
3	5000	81.	85.7	96.6	92.	.0575	.686	2.6	1.5	.60	.5	28	55

DISCUSSION OF RESULTS.

CALIBRATION OF INSTRUMENTS. -- No thing further need be added under this head to what was said in the beginning, except a source of error, which will apply equally well to allthe other measurements. The variableness of the voltages, mentioned before, introduces no small chance of error, especially, as inthe case of the two voltmeters, when the instruments are not equally sensitive, and where for any reason the formulas for calculating results demand close accuracy.

LOSSES AND EFFICIENCIES. -- The iron losses as shown by these tests are well within the limits of good design, as shown by the following comparison of values found and those given as maxima in Jackson's "Alternating Currents ".

~~Capacity~~. TESTED.			FROM JACKSON.		
Capacity.	Iron Loss.		Capacity.	Iron Loss.	
Watts.	Watts.	Per Cent.	Watts.	Watts.	Per C.
1500.	32.2	2 3-8%	1500.	40.	2 2-3%
2500.	, 44.3	1.8	2500.	60.	2.4
5000.	81.	1.6	4000.	80.	2.

The above comparison is hardly fair to the machines of this test, since the iron losses have been corrected for 104 Volts secondary pressure, while those recorded in Jackson are correct for 100. Volt pressure.

The C^2R. losses at full load are No.1. 2.1%; No.2. 1.9% and No. 3. 1.7% of the out-put, which falls within the limits set

by Mr.Jackson of 1 1-2 to 3 1-2 per cent. of the out-put. The efficiencies make an equally good showing with those recorded. Only one test, that on a 1 1-2 Kilo-Watt Transformer in the table contained in Mr.Jackson's Volume, showed as high an efficiency as that given by No.1. The average was about 1 1-2% below. No.2.compared even more favorably with the one transformer of equal capacity tested by Mr.Ford; it had a maximum efficiency of 96.5, as against 92.5% of the latter. I could find no record of tests on 5000. Watt transformers. In allcases the efficiencies were maximum at full load. The foregoing comparisons, however speak a little more favorably for the transformers of this test than seems justifiable, since the frequency of the local system is 133 periods per second, while that used in the tests recorded by Mr.Jackson and Mr.Ford was 125. periods. A reduction to the lower frequency would slightly increase the losses. The per cent. efficiency would probably be lowered from one to two tenths.

The all day efficiency is the percentage of the total energy (Watt-hours) put into the transformer in twenty-four hours to what is given out by the transformer in the same time. The conditions assumed, of five hours on full load out of twenty-four, are probably more favorable, than those usually met with in practice. Transformers used in incandescent lighting are seldom fully loaded, for rarely are all the lamps in its secondary, burning at the same time.

The efficiencies, both maximum and all-day, increase with the size of the transformer.

REGULATION.-- A more marked improvement was shown in

regulation than in efficiency for increased capacity, as a comparitive look at the full load drops will show.

Transformer No.1., 56 Volts; No.2. 3.1 Volts; No.3, 2.4 Volts. The drop in No.1. seems excessive; the author intended to check the results by a second experiment, but the transformer was sent out on the line before it could be done. Some error in this test seems more probable from the large leakage drop of No.1. 3.4 Volts; No.2. shows comparatively small leakage of 1 Volt, while No.3. has only .5 Volts.

The Cr.drop in the three machines remains practically the same, slightly favoring the larger units, while the proportionally CR. drop decreases directly with increase in the capacity: the percentage leakage drop, shows even more marked decrease, varying more nearly in the inverse ratio of the squared capacity.

HEATING. -- For reasons, unnecessary to state here, it was impossible to test for heating of transformers in oils, as was hoped. The determinations of rise in temperature, from the relations connecting the electrical resistance of copper, and its heating, probably suffered larger chances of error from the fluctuating character of the current than any other deductions. It is readily seen from the formulae, $b = a - \frac{Ra. - Rb.}{Rb.}$, that with $d = .004$, small variations in Ra. and Rb. might be considerably magnified in the value of b.

In all cases average values of resistances were taken, and the results obtained probably closely approximate the truth. To illustrate the range of error, to which they were subject,-

the rise in temperature calculated from maximum cold resistance and the minimum hot resistance, is subtracted from rise obtained from minimum cold resistance , and maximum hot resistance. The result gives the range of error.

TRANSFORMER.	LOAD.	RISE. Max.	Min.	RANGE, OF Error.
No.2.	Open C.	42°	37.°	5.°
No.2.	Full L.	59.7	50.5	9.2°
No.3.	Open C.	32.	23.	9.
No.3.	Full L.	67.	30.	37.

This fluctuation in readings, especially on full load, was not due to heat being radiated from the machine, for the resistances calculated from successive readings, tended to increase rather than decrease. A circuit of more constant voltage is needed for accurate results.

CONCLUSIONS.

Though these tests are too incomplete to establish conclusively any general laws, yet some facts of general application can be deducted from them.

The larger the unit, the smaller the proportional core loss. It is doubtless possible in larger machines to obtain closer joints and better lamination, thus reducing magnetic reluctance and cutting down foucalt current loss.

The greater the capacity of the transformer, the better the regulation. This result seems tobe obtained principally

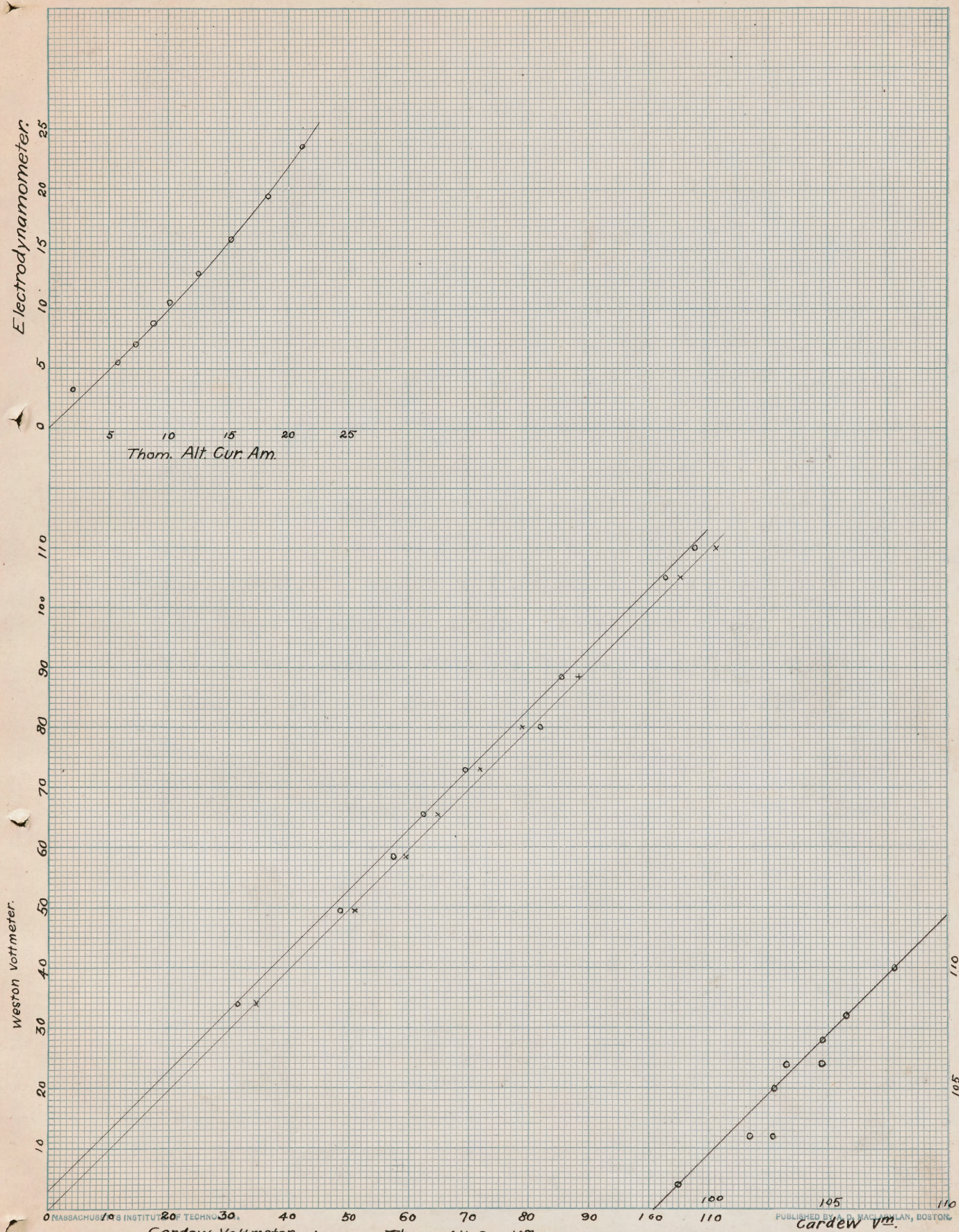
throught the elimination of the leakage drop, though there is also a great proportional decrease in the Cr.drop.

In calculating the all-day efficiency of transformers, which run much of the time on open circuit, such as in incandescent lighting, the core losses is a more important factor, than the copper losses, and those transformers having lowest iron losses give best results.

The maximum efficiency in each of the transformers tested was obtained at full load. As suggested by Mr.Ford in his tests this does not seem the most economical arrangement for incandescent lighting systems, since during the period of loading(about five hours), the demand will not average above two-thirds to three-fourths rated capacity. It would seem well therefore to design for a maximum efficiency at about this percentage of capacity, when intended for such running conditions.

These tests owe their existance largely to the kindness of Mr.R.T.Scott, Electrician for the Knoxville Power & Traction Company, who furnished the transformers and facilities necessary to making the experiments.

Plate I.

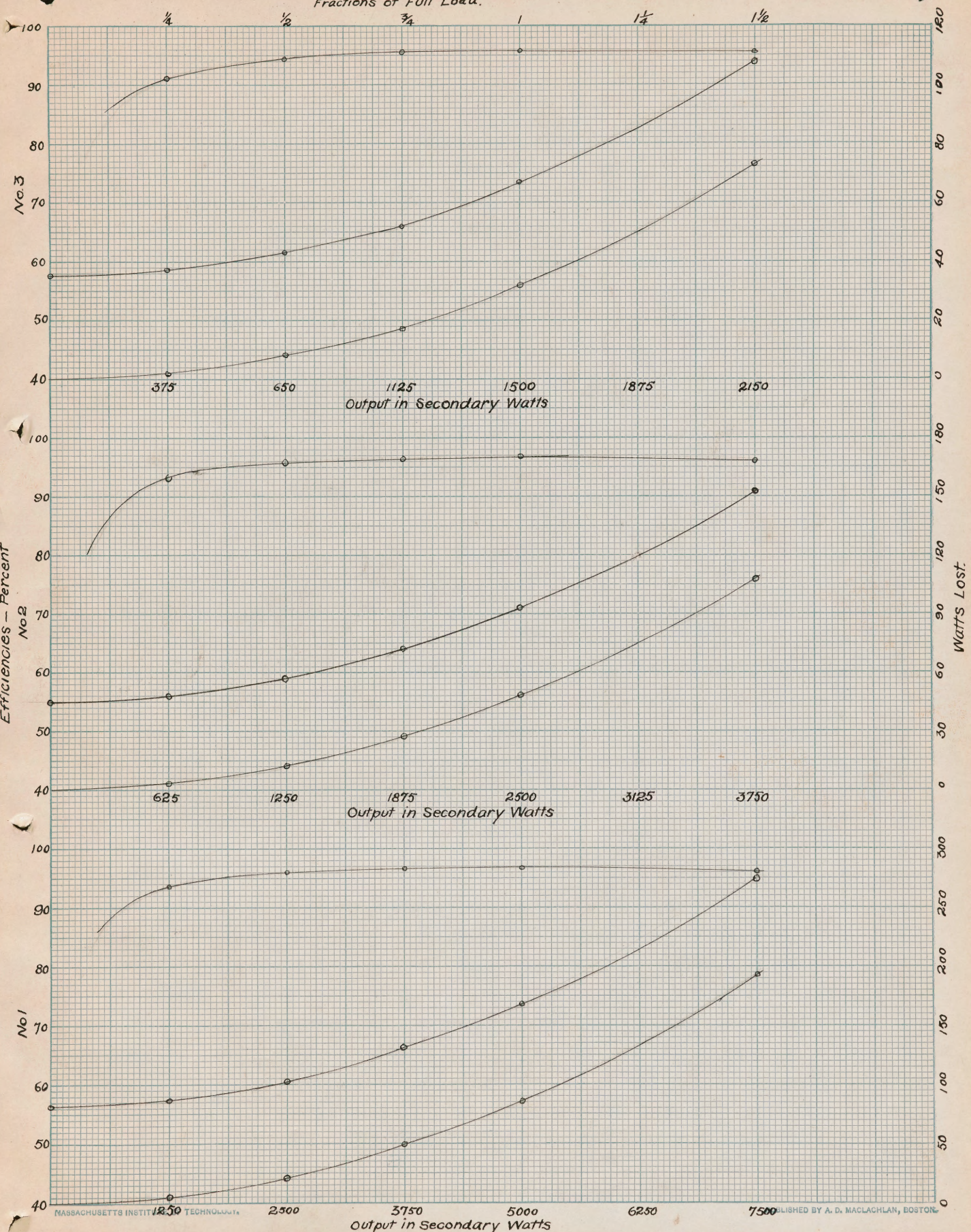


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Plate 1.

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Plate 2.

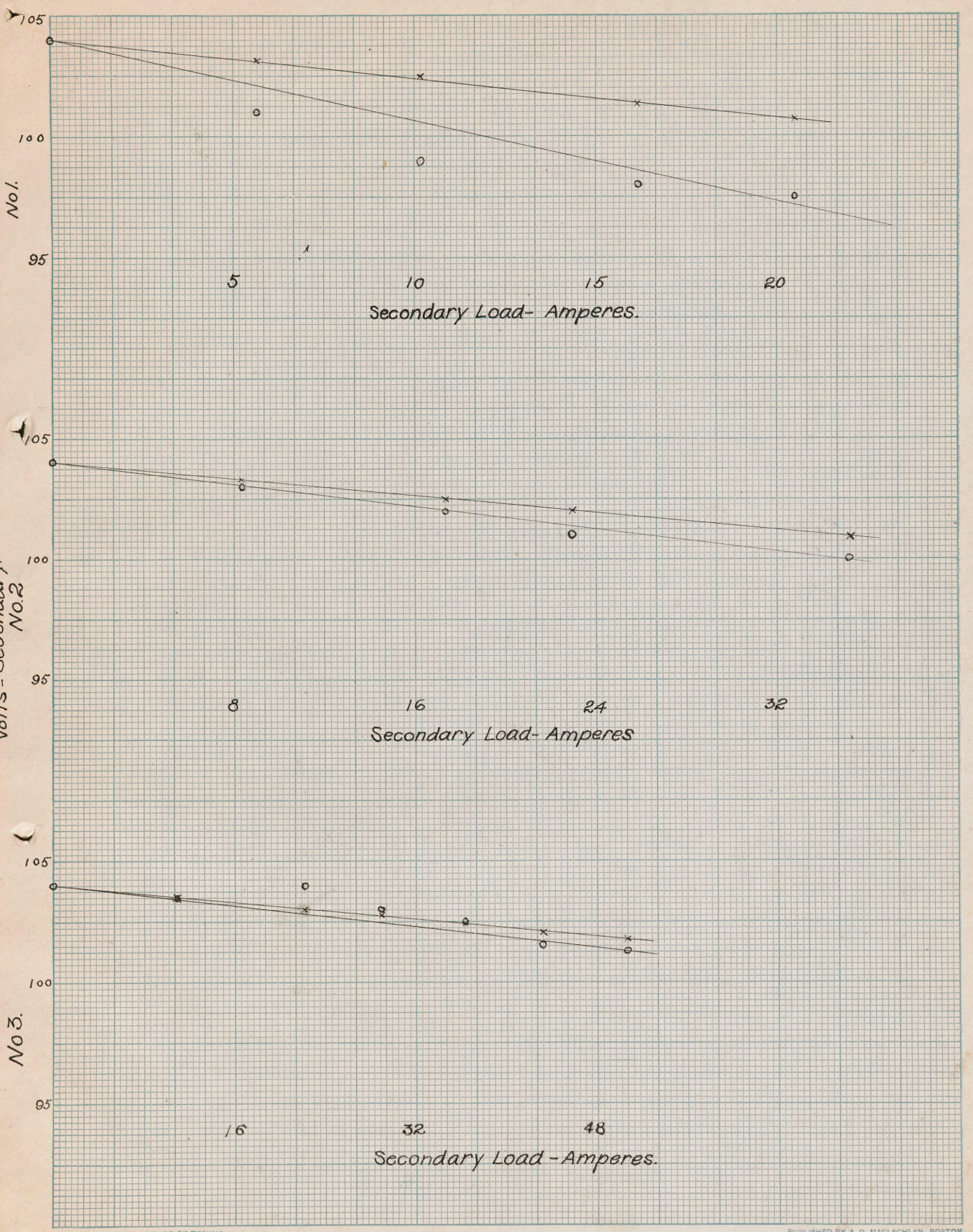


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Plate 2.

Plate 3



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o = Total Drop
x = CR Drop

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Plate 3.