Wilson, Barton & Wolff

Performance of an Induction Motor

Electrical Engineering
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PERFORMANCE
OF AN
INDUCTION MOTOR

BY

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THESIS

FOR THE DEGREE OF BACHELOR OF SCIENCE

IN

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IN THE

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OF THE

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PRESENTED MAY 1902.

UNIVERSITY OF ILLINOIS

May 29, 1902.

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Thomas Wilson, William F. Borton, and Salomon Wolff

ENTITLED Performance of an Induction Motor

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Electrical Engineering.

Morgan Brooks

HEAD OF DEPARTMENT OF Electrical Engineering.

T A B L E O F C O N T E N T S.

INTRODUCTION.

The polyphase induction motor has so many advantages over other types of motors that it is rapidly replacing them. Chief among these advantages is the fact that there are no brushes or commutator to cause trouble. This is a very distinct gain since, by the absence of these two features, a motor is produced which requires absolutely no attention except in regard to the bearing surfaces. Another advantage is that, in consequence of the primary winding being stationary, better insulation and hence a comparatively high voltage may be used where the distance from generator to motor is short; this doing away with transformers. In case the distance of transmission is long, step-up and step-down transformers may be used, thus reducing the line loss very materially. In any case the induction motor is an efficient machine and highly satisfactory in operation.

All these facts make the induction motor an interesting machine to investigate.

OBJECT and GENERAL PRINCIPLES.

The tests described herein were made upon a 40-horse-power, 440-volt, two-phase,8-Pole, 60-cycle, induction motor built by the Westinghouse Electric & Manufacturing Co. and may be taken to represent normal conditions in the "Performance of an Induction Motor".

This motor is of the squirrel-cage type, consisting of two simple elements, i. e., a stationary part permanently connected to the main circuits, and a rotating part having no electrical connection with any extrenal circuit, and having no electrical contacts or adjustments, in fact, no sliding or working friction, except that of the shaft in the journals. The only parts that can wear, therefore, are the shaft and journal boxes. Self-oiling bearings provide lubrication thus reducing the attendance to a minimum.

The polyphase induction motor, the invention of Nicola Tesla, has two main elements; the primary, which is directly magnetized by the currents supplied from the power circuit; and the secondary, in which currents are induced by the action of the primary. The windings of the primary are so arranged that when supplied with alternating currents differing in phase, i.e., polyphase currents, a rotating magnetic field is produced. This field acts upon the secondary winding, and induces current therein.

Mechanical rotation ensues, provided by the action between the secondary currents and the rotating field of the primary. In order that currents may be induced in the secondary and thus torque produced, it is necessary that the rotor shall run at a speed slightly below that of the primary revolving magnetic field; the difference in the two speeds being known as the slip. This necessity may be explained as follows: "electro-motive force" is required to drive the currents through the secondary winding. To produce this "electro-motive force" there must be relative motion between the conductors on the secondary and a magnetic field, in this case the rotating magnetic field set up by the primary. This relative motion can only occur when the rotor is revolving at a speed other than synchronous speed. When a load is thrown on motor the slip increases. This increases the "electro-motive force" and hence the current in the rotor to a point such that the torque necessary to sustain this load is developed.

DESCRIPTION of APPARATUS.

Two phase alternating current for the tests was furnished by a 75 K.W. Westinghouse, revolving armature, belted type generator. The generator has five pairs of poles and has besides its separate field exitation a composite winding which compensates for the change in voltage with varying load.

The prime mover was a tandem compound Ideal Steam Engine built by A.L.Ide and Son and is connected to the generator through belting and a counter shaft.

The particulars of motor used in this test is as follows.

Particulars of Motor.

Type of machine,	Induction Motor.
Number of poles,	8.
Capacity: H.P. (normal full load),	40.
Speed R.P.M. (synchronous),	900.
Volts,	440.
Frequency,	60.
Total weight (lbs),	1920.

Particulars of Stator.

Diameter, internal, of core-disks	22-1/8".
Diameter, external, of core disks,	24-1/8".
Effective length of iron parallel to shaft,	7-7/8".
Number of slots,	96.
Number of poles,	8.

Slots per pole,	12.
Slots per pole per phase,	6.
Depth of slots,	1-1/8".
Width of slots,	3/8".
Width of teeth,	5/16".
Weight of stator without end brackets,	1025#.

Particulars of Rotor.

Diameter, external, of core disks,	22".
Diameter, internal, of core disks,	18".
Effective length of iron parallel to shaft,	7-3/4".
Gross length of iron between heads,	7.3/4".
Number of slots,	72.
Depth of slots,	25/64".
Width of slots at base,	33/64".
Width of teeth at base,	13/32".
Number of conductors in slot,	1.
Depth of each conductor,	3/8".
Width of each conductor,	1/2".
Extreme length of each conductor,	13-13/16".
Kind of winding,	Squirrel-cage.
Depth of each short-circuiting ring,	3/4".
Width of each short-circuiting ring,	1-9/16".
Number of arms in spider,	5.
Outside diameter of spider hub,	6-3/4".

Width of spider arms,	3".
Thickness of spider arms,	1-1/8".
Length of spider hub,	6-1/2".
Diameter of shaft, bearing portion,	2-3/8".
Diameter of shaft, core portion,	3-1/4".
Diameter of shaft, pulley fit,	2-3/8".
Weight of rotor,	285#.

-:-

Power was absorbed by means of a Prony-brake consisting of cast-iron brake-wheel having inward projecting flanges so as to allow for the circulation of water. The brake shoes were made of hard maple and the lever-arm of brake was of such length that the circumference of a circle traced by it would be just 33 feet. The friction in this brake occured between the brake shoes and the brake wheel, which was put on shaft of the motor in place of the belt pulley. The pull on the brake-arm was measured by means of a "Buffalo",platform scale which was found more satisfactory than a spring balance.

A Manhattan A.C. inclosed arc lamp with Manhattan regulator machine was used in determining slip.

The speed indicator consisted of a small direct-current magneto machine belted to motor shaft. As this is a magneto machine the field is constant; the voltage,therefore, varies

directly as the speed. The indicator may then be calibrated by taking readings of speed with a common speed indicator and readings of voltage from the magneto machine. The ratio of the two readings having been determined, the speed of the machine under test may be obtained by simply multiplying the volt-meter readings by this ratio.

A testing table was made especially for this work. Switches were provided for short circuiting the current coils of watt-meters and ammeters, the main switch only one side of each phase. A three way switch made it possible to read voltage before closing main switch and after starting,by a quarter turn of same switch,the voltage terminals were connected directly to the terminals of motor. The wiring for current carrying was always doubled back on itself to avoid disturbing effects on the ammeters and watt-meters.
See plate Number 18.

MEASURING INSTRUMENTS.

Weston volt-meters reading to 150 volts on the upper scale were used with a multiplier of four. The voltage could be easily read to 2/10 of a scale division or, multiplying by four, say, to the nearest volt.

The ammeters were of the Thompson type reading up to 100 amperes. The scale is graduated to amperes, but tenths of amperes can be estimated.

The wattmeters were Weston instruments having a maximum capacity of 50 amperes at 150 volts. Multipliers of four were used. In case of readings exceeding the normal current range of the wattmeters, the short-circuiting switch made it possible to apply the current for only the time actually needed to obtain a reading, thus preventing any damage to instruments. Power readings could be taken down to 50 watts, which with the multiplier made consecutive readings differ by 200 watts.

METHOD of TESTING.

In studying the performance of this induction motor, runs were taken at five different voltages. The load, applied by means of the Prony brake, was varied, starting at zero lead and gradually increased. Readings of voltage, current and power were taken in each phase also readings for frequency, speed, torque and slip. From these data the following items were computed; power factor for each phase, input, output, true and apparent efficiencies, % slip and horse-power. The power factors for each phase were computed by formula W/EI, which equals actual watts in circuit or wattmeter reading divided by apparent watts or product of voltage and currcent readings.

To obtain the total input we simply added together the input for each phase giving the actual watts delivered to the motor.

Computed output from brake horse-power; multiplied by 746 to obtain watts.

The true efficiency is output divided by input.

The apparent efficiency is output divided by apparent watts input.

The method of getting slip is fully explained elsewhere.

Brake horse-power, owing to the length of brake arm, was obtained simply by multiplying the pressure on scale (weight) by the number of thousands of R.P.M's of the motor.

These quantities, computed as stated above, were taken and in order to compare results more easily the following curves were plotted;- power factor, current and input for each phase on an output base; true and apparent efficiencies, percent slip and total input on an output base; current and output on a slip base. The comparisons and conclusions drawn from these curves are taken up later in a discussion of the curves.

At least two runs were taken in each case and a selection of the best run was made.

We were not able to load motor until it would stop on account of the incapacity of the brake to carry sufficient load. Our data, therefore although very satisfactory, would probably have been more instructive had the brake been of sufficient size to load motor until it stopped.

SEPARATION of LOSSES.

The losses in the induction motor may be divided into friction, copper, hysteresis and eddy current losses.

The friction loss was determined by each of the three following methods:-

(a) The induction motor was directly connected to a D.C. motor by means of a flexible coupling. The input of D.C.motor was measured when it was driving the induction motor light, and also when it was disconnected from the induction motor, supplying only its own losses. The difference in the two determinations of durect-current input, less the increased I^2R loss in the motor's armature and field when driving the induction motor, should give the friction of the induction motor at same speed.

Let I_1, be current in D.C. motor when driving induction motor

" R " resistance of motor armature.

" r " " " " field.

" I_2 " current in D.C. motor running light.

" W_1 " input " " " when driving induction motor

" W_2 " " " " " " running light.

Then friction loss of motor is equal to

$$(W_1 - I_1^2 R - I_1^2 r)-(W_2 - I_2^2 R - I_2^2 r)$$

Following are results as obtained.

Input of D.C. motor driving 40 H.P. induction motor,

$I = 21$, $I_a = 20.2$, $E = 47.5$, $EI_1 = 997.5$, $I_f = 0.8$, R.P.M. = 900

Input of D.C. motor running light,

$I = 3.3$, $I_a = 2.5$, $E = 43.5$, $EI_2 = 137$, $I_f = 0.8$, R.P.M. = 900

Resistance of motor armature 0.112 ohms.

Friction of 40 H.P. motor equals,

$(input_1 - I_a^2 R - I_f^2 r) - (input_2 - I_a^2 R - I_f^2 r)$

equals 997.5 - 45.5 - 137 1.22 = 816 watts.

(b) The motor was driven at normal speed with known load on brake. Then current was cut off and speed motor noted every 5 seconds until motor stopped running. Repeated this with no load on motor. The retardation curves (speed on a time base) were plotted, and tangents drawn to these curves at points of normal speed.

Let α be the angle made by tangent with horizontal axis at no load;

α' be the angle made by tangent with horizontal, azis at known load;

q be power absorbed by brake.

Then friction $q \dfrac{\tan\alpha}{\tan\alpha' - \tan\alpha}$ (See Plate 4.)

(c) the input and slip were measured for small loads on motor, and input plotted as abscissae and slip as ordinates. For small loads the slip line will be a straight line. If we produce the slip line till it cuts the input axis we get the input at zero slip which is of course the friction loss.

Determination of Hysteresis
and
Eddy-Currents by Stray-Power Method.

We have already determined friction losses and may assume them proportional to speed. We then get the stray power in watts and divide by the voltage to get the power component of the current i.e. I cos.ϕ. We varied the voltage keeping the frequency proportional to the voltage, thus keeping the flux density and hence the magnetizing current constant. Several readings were taken at different points and the value of I cos.ϕ plotted on a voltage base, (See Plate 2), and drew a straight line through the points. Taking any point on this curve we can get the stray power for that point by simply multiplying the voltage at that point by the corresponding value of I cos.ϕ. Since friction is proportional to speed and hence to voltage, a straight line parallel to the axis of "X" and at a distance from it equal to friction in watts divided by 440,

(the friction losses having been determined at 440 volts) will represent friction loss, which same subtracted from the total stray power will leave only hysteresis and eddy current losses. To separate hysteresis and eddy current losses, we produced the line till it cuts the axis of "Y". Through this point of intersection we drew a line parallel to the axis of "X". We now divided our ordinate into two parts, that is after friction has been subtracted; i.e., a constant part corresponding to hysteresis loss, and an increasing part corresponding to the eddy current loss; to get the loss in watts we simply multiplied these values by the corresponding voltage.

Determination of Copper Loss.

To determine the copper(I^2R) loss we blocked the rotor and applied a reduced voltage, reading current and watts and increasing the current up to and above full load value. At this low voltage the hysteresis and eddy current losses are practically negligible. With rotor blocked the motor acts as a transformer with secondary short-circuited, and a wattmeter placed in the separate phase of the primary will measure the copper loss of both primary and secondary, i.e., stator and rotor. We can get the stator I^2R by measuring R and multiplying it by the square of the current for any value

of current, and by subtracting these values from the total I_2R loss get I_2R for rotor. (See Plate 1)

IN General.

The first two methods of determining friction agreed fairly well; the third method looked nice on paper but didn't work out good in practice, giving a result nearly three times that given by the first two methods.

As regards hysteresis and eddy current losses, they may be some what at variance as it was exceedingly difficult to keep the frequency constant when engine was running below normal speed. We repeated this test several times and took the best run, but even then the points do not form a very straight line, as they should do.

No trouble was experienced in determining the I^2R loss and the results were apparently accurate and satisfactory.

HEAT RUN.

Motor was run for six hours under full load and normal voltage and frequency, the load being supplied by running several loaded generators from line shaft to which the motor was belted. Input of the motor was measured by means of wattmeter placed in the primary circuit and multiplying by the efficiency we obtained output. The rise in temperature was measured by means of a thermometer and also determined it from the increase in resistance. The temperature of the room was 24° C. as measured by the thermometer at the start and motor assumed to heat the same temperature. At the end of run the thermometer when thrust into motor measured a temperature of 50° C showing a rise of 26° C. This is undoubtedly low since the bulb of the thermometer could not be covered over.
The average resistance of the stator circuits was 0.312 ohms at start and 0.341 ohms at the end, showing an increase of 0.039 ohms. The per cent rise was 12.9% corresponding to a rise of temperature of 32.4°. This rise in temperature is low and tends to show that the motor is under rated.

METHOD of DETERMINING SLIP.

A disc six inches in diameter, the surface of which was divided into sixteen alternately black and white sections, was attached directly to the shaft of the 8 pole motor. An alternating inclosed arc lamp was suspended from ceiling . That the arc was on same level as center of disc and about 2 ft. from same. The lamp was tapped into one phase of the motor supply and at such a point that the power absorbed by lamp was not measured by the instruments employed in test. By refering to plate No.   the diagram of connections shows that the lamp in no way effected the load on motor. The disc and lamp were surrounded by a canvas screen so as to exclude all light except that from the arc. If the motor revolved synchronously the intermittent flashes of the alternating arc fed from same source of a.c. would illuminate the black and white sectors at the instant they had advanced 1/8 of a complete turn, and as the disc carries eight equally spaced sectors there will be no apparent motion of the sectors. If however the disc is moving at a rate below synchronism due to "slip" of motor, the sectors will have have advanced something less than 1/8 of a revolution between flashes and will appear to move back ward slowly. If the displacement amounts to one apparent revolution of the disc to ten actual revolu-

tions of the motor the slip is 10% or the number of black sectors passing a given position per second divided by frequency gives percentage of slip.

Let A equal the number of sectors which seem to pass a given point in one minute.

Let B equal the number of black sectors on disc.

" P " " " " pairs of poles in motor.

" f " frequency of supply.

then % slip equals $\frac{A \times P}{B \times f \times 60}$

This method of determining slip proved to be very accurate and satisfactory.

METHOD of DETERMINING FREQUENCY.

The direct method of determining frequency is of course to multiply the number of pairs of poles of generator by its R.P.M. and divide by 60. This was too cumbersome a method, so we used a frequency meter. The meter was constructed as follows:- A piano steel wire is suspended from one end with a weight at the other end to keep it taut. A small electro-magnet, with a core composed of a bundle of soft iron wires is fixed near to and at right angles to the vertical wire. When this magnet is energized by an alternating current it sets the adjacent wire into vibration. It is a well known fact that the maximum amplitude of vibration is attained only for a definite length of wire or multiple of that length corresponding to a complete period or multiple of same. Then if we adjust the length of wire by means of a clamp till we get maximum amplitude of vibration we know that we have a length of wire proportional to the frequency. By means of a properly calibrated scale we can read the frequency directly by simply adjusting clamp for maximum vibration.

DISCUSSION of CURVES.

By referring to plate No. 1 it will be seen that for full load current of 35 amperes the total I^2R losses are practicallyl.2 K.W. The I^2.R. losses in stator are .8 K.W.; leaving 0.4 K.W. loss in rotor. In other words 4.% of total output at full load is lost in heat; 2.65 % being lost in the stator and 1.35% lost in rotor.

Plate No. 2 shows that the friction and hysteresis losses are about equal. For normal voltage (440) the friction loss is 700 watts and the hysteresis loss is 900 watts. The loss due to eddy currents is only about 100 watts.

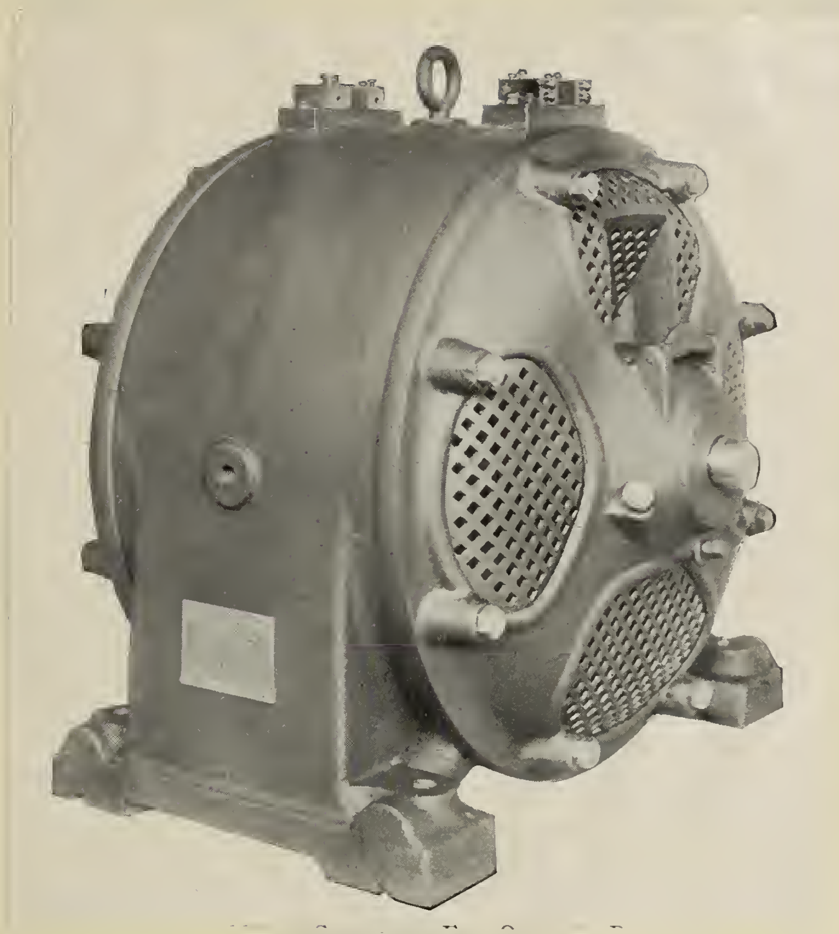
Plate No. 3 shows that at full load the I^2.R. losses are just about equal to all the other losses. The theoretical efficiency, as shown at various loads, runs from 3 to 7% higher than the actual efficiency, as shown by plate No. 7 with machine running at normal voltage. At full load the actual efficiency is about 5% lower than the theoretical.

Plate No. 4 shows the results of two methods of determining friction losses. These methods did not check as is evident from inspection. The retardation method, checked very well with the direct connection method as described under methods of determining friction losses.

In comparing the true efficiency curves for runs at different voltages, as shown by plates No. 5, 6, 7, 8 and 9,

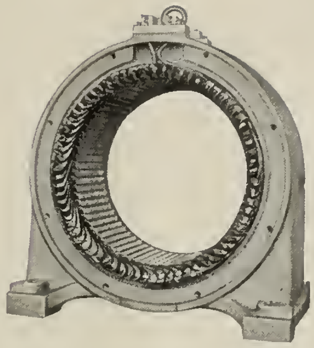
we see that the machine developes its maximum efficiency when running at 400 volts. These curves show that for the 400 and 500 volt runs the efficiency increases for overloads while in all other runs the efficiency falls off when machine is overloaded. The curves showing slip are quite similar except in the 300 volt run when it goes up to 5 1/4% instead of up to 2 1/2 or 3%. The input curves vary inversely as the efficiency curves. The power factor increases quite rapidly when the machine is run at 300 volts, as shown by plate No. 10, reaching 90% at 1/2 load. This emphasizes the fact that a high power factor is not always indicative of a high efficiency. In the 400 and 440 volt runs the power factor reaches 90% only at about full load, while in the 500 volt run it reaches 90% at 30% overload. In the 580 volt run it gets no higher than 80% at full load.

Plates 14, 15 and 16 show that practically the current and output vary directly as the slip; also that the no load current and hence the magnetizing current varies directly with the voltage.

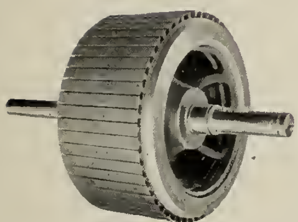


Cast-iron Housing.

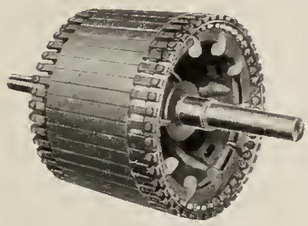
Primary Ready for Winding.



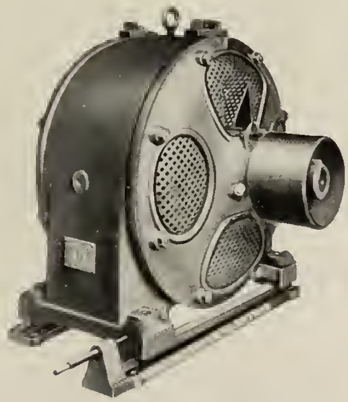
Primary Completely Wound.



Secondary Core.

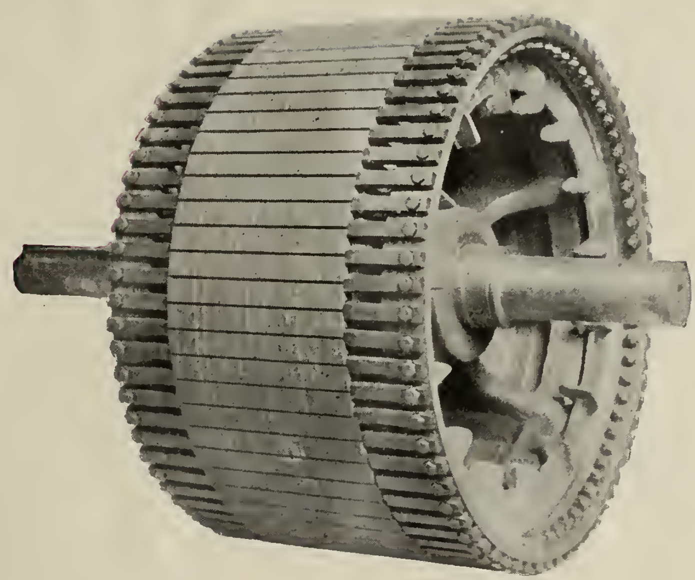


Secondary Complete.



Type "C" Motor Complete.

CONSTRUCTION
OF A TYPICAL
TYPE "C" MOTOR.



Secondary Complete, Showing Copper Bars Connected to End Rings.

40 HP. 2-PHASE, INDUCTION MOTOR.

E = 300V.

1	2	3	4	5	6	7	8
Nº	PF_1	$P.F_2$	INPUT W_i	OUTPUT W_o	TOTAL EI	TRUE EFF. $\% = \frac{W_o}{W_i}$	APP. EFF. $\% = \frac{W_o}{EI}$
1	.199	.104	1.08	0	7.26	0	0
2	.568	.598	5.52	3.38	9.49	61.2	35.6
3	.731	.759	9.12	6.74	12.3	74.0	55.0
4	.810	.848	12.8	10.1	15.4	79.0	65.7
5	.830	.868	16.2	13.4	19.1	82.8	70.2
6	.864	.907	19.8	16.7	22.4	84.2	74.5
7	.898	.935	23.8	19.8	26.0	83.0	76.0
8	.892	.943	27.7	22.9	30.2	82.5	75.9
9	.900	.916	31.6	25.8	34.8	81.5	74.0
10	.890	.920	35.2	28.7	38.9	81.5	74.0
11	.902	.920	39.8	31.4	43.7	79.0	72.0
12	.878	.900	43.0	34.3	48.5	79.7	70.8

40 HP, 2-PHASE. INDUCTION MOTOR.

E = 300V.

1	2	3	4	5	6	7	8	9
Nº	E_1	I_1	W_1	E_2	I_2	W_2	E_1I_1	E_2I_2
1	297	11.5	.68	296	13.0	.4	3.41	3.85
2	308	16.7	2.92	300	14.5	2.6	5.14	4.35
3	300	21.5	4.72	297	19.5	4.4	6.45	5.80
4	300	27.0	6.56	298	24.5	6.2	8.10	7.31
5	301	32.5	8.40	300	30.0	7.8	10.1	9.00
6	305	38.5	10.2	304	35.0	9.6	11.8	10.6
7	305	44.5	12.2	304	41.0	11.6	13.6	12.4
8	308	51.5	14.2	306	47.5	13.5	15.9	14.3
9	310	58.0	16.2	306	55.0	15.4	18.0	16.8
10	308	65.5	18.0	306	61.0	17.2	20.2	18.7
11	305	73.5	20.2	304	70.0	19.6	22.4	21.3
12	304	82.5	22.0	300	78.0	21.0	25.1	23.4

40HP, 2-PHASE, INDUCTION MOTOR.

E=300V.

1	2	3	4	5	6
No.	∽	SLIP %	R.P.M.	T LBS.	HP.
1	60.9	.12	909	0	0
2	60.9	.49	908	5	4.54
3	60.9	.87	904	10	9.04
4	60.9	1.18	901	15	13.5
5	60.9	1.55	898	20	18.0
6	60.9	1.86	895	25	22.4
7	60.7	2.35	889	30	26.6
8	60.7	3.61	877	35	30.7
9	60.1	3.84	867	40	34.7
10	60.1	4.84	858	45	38.5
11	59.7	5.96	842	50	42.1
12	59.7	6.39	838	55	46.1

40 HP. 2-PHASE, INDUCTION MOTOR.

E = 400V.

1	2	3	4	5	6	7	8	9
№	E_1	I_1	W_1	E_2	I_2	W_2	E_1I_1	E_2I_2
1	398	14.2	.2	402	14.8	1.00	5.66	5.95
2	394	17.3	3.12	396	18.0	2.20	6.81	7.14
3	398	21.0	4.96	398	20.2	3.87	8.37	8.05
4	402	24.6	6.96	402	23.2	5.87	9.90	9.35
5	398	28.2	9.08	398	26.8	7.52	11.2	11.7
6	399	32.2	10.6	399	30.3	9.52	12.8	12.1
7	402	36.3	12.3	402	33.8	11.2	14.6	13.6
8	398	40.7	14.0	398	38.3	13.0	16.2	15.2
9	400	44.8	16.2	400	42.4	14.8	17.8	17.0
10	400	49.8	17.8	400	47.5	16.8	19.4	19.0
11	400	55.0	18.4	400	52.0	18.5	22.0	20.8
12	400	56.0	19.2	402	56.2	20.5	22.4	22.6
13	400	63.0	22.0	402	62.2	22.1	25.2	25.1

40 HP. 2-PHASE, INDUCTION MOTOR

E = 400V.

1	2	3	4	5	6	7	8
Nº	PF_1	PF_2	INPUT W_i	OUTPUT W_o	TOTAL EI	TRUE EFF. $\% = \frac{W_o}{W_i}$	APP. EFF. $\% = \frac{W_o}{EI}$
1	.354	.132	1.20	0	11.6	0	0
2	.466	.316	5.32	3.48	14.0	65.2	24.8
3	.493	.480	8.83	6.97	16.4	78.6	42.5
4	.710	.630	12.8	10.4	19.3	83.8	52.3
5	.810	.710	16.6	13.7	22.9	82.5	59.8
6	.822	.800	20.1	17.1	24.9	85.0	68.7
7	.845	.835	23.5	20.5	28.2	87.2	72.5
8	.863	.857	27.0	23.8	31.4	88.0	75.8
9	.905	.872	31.0	27.1	34.9	87.5	77.8
10	.894	.880	34.6	30.3	39.0	87.5	77.7
11	.890	.892	37.9	33.6	42.8	88.5	78.5
12	.855	.908	39.7	36.5	45.0	92.0	81.0
13	.870	.888	44.1	39.6	50.3	89.7	78.7

40 HP, 2-PHASE, INDUCTION MOTOR,

E = 400 V.

1	2	3	4	5	6
Nº	∽	% SLIP	R.P.M.	T LBS.	HP
1	62.0	.07	934	0	0
2	62.0	.26	933	5	4.67
3	62.0	.43	932	10	9.34
4	61.7	.63	929	15	13.9
5	61.7	.83	920	20	18.4
6	61.7	1.02	918	25	23.0
7	61.4	1.22	915	30	27.5
8	61.4	1.44	912	35	32.0
9	61.4	1.53	908	40	36.3
10	61.4	1.66	905	45	40.7
11	61.4	2.07	900	50	45.0
12	60.5	2.26	890	55	49.0
13	60.6	2.66	884	60	53.0

40 H.P. 2-PHASE, INDUCTION MOTOR.

E = 440 V.

1	2	3	4	5	6	7	8	9
No.	E_1	I_1	W_1	E_2	I_2	W_2	E_1I_1	E_2I_2
1	439	19.0	1.2	441	19.0	4	8.1	8.4
2	442	20.0	3.5	443	19.8	2.6	8.8	8.8
3	440	22.0	5.3	443	21.6	4.4	9.7	9.6
4	442	25.0	7.4	443	24.0	6.2	11.1	10.6
5	441	28.0	10.2	443	26.8	8.0	12.4	11.9
6	443	31.5	11.0	445	29.0	9.0	14.0	12.9
7	440	34.5	12.6	441	33.5	11.0	15.2	14.8
8	442	38.5	14.4	440	38.0	13.7	17.1	16.8
9	440	42.0	16.8	441	41.3	15.0	18.5	18.2
10	441	45.5	18.2	439	45.0	17.2	20.1	19.8
11	441	47.5	19.6	443	49.0	19.5	21.0	21.7
12	440	51.5	21.2	443	52.0	20.0	22.7	23.0
13	440	60.5	24.3	443	58.0	23.2	26.8	25.7

40 HP. 2-PHASE, INDUCTION MOTOR.

E = 440 V.

1	2	3	4	5	6	7	8
No.	PF_1	PF_2	INPUT W_i	OUTPUT W_o	TOTAL EI	TRUE EFF. $\% = \frac{W_o}{W_i}$	APP. EFF. $\% = \frac{W_o}{EI}$
1	.148	.048	1.6	0	16.5	0	0
2	.398	.296	6.2	3.4	17.7	53.2	19.4
3	.520	.460	9.7	6.8	19.8	70.0	34.5
4	.660	.615	13.6	10.2	21.7	75.0	47.0
5	.821	.672	18.2	13.6	24.3	74.8	56.0
6	.787	.700	20.0	17.0	26.9	85.0	63.2
7	.830	.743	23.6	20.3	30.0	86.0	67.7
8	.840	.815	28.1	23.7	33.9	84.5	70.0
9	.910	.823	31.8	27.2	36.7	85.8	74.0
10	.907	.869	35.4	30.0	39.9	85.0	75.0
11	.934	.900	39.7	33.4	42.7	84.0	78.0
12	.932	.870	41.2	36.6	45.7	89.0	80.0
13	.907	.903	47.5	39.9	52.5	84.0	76.0

40 HP, 2-PHASE, INDUCTION MOTOR.

E = 440V.

1	2	3	4	5	6
№.	∽	% SLIP	R.P.M.	T LBS.	HP
1	61.4	.09	920	0	0
2	61.4	.27	918	5	4.6
3	61.4	.39	917	10	9.2
4	61.2	.56	915	15	13.7
5	61.2	.72	913	20	18.3
6	61.2	.85	912	25	22.8
7	61.2	1.03	910	30	27.3
8	61.1	1.22	908	35	31.8
9	61.1	1.44	906	40	36.2
10	60.5	1.56	895	45	40.3
11	60.5	1.68	894	50	44.7
12	60.5	1.83	892	55	49.0
13	60.5	2.14	890	60	53.4

40 H.P. 2-PHASE, INDUCTION MOTOR.

E = 500 V.

1	2	3	4	5	6	7	8	9
Nº	E_1	I_1	W_1	E_2	I_2	W_2	E_1I_1	E_2I_2
1	500	21.5	1.6	500	21.5	.4	10.8	10.8
2	501	22.0	3.1	503	22.0	2.4	11.1	11.7
3	500	24.0	5.4	500	23.5	4.4	12.0	11.7
4	499	26.0	7.4	503	25.0	6.0	13.0	12.6
5	498	28.5	9.2	500	27.0	8.0	14.2	13.5
6	498	30.5	11.2	496	29.5	9.1	15.2	14.6
7	502	33.0	12.6	504	32.0	11.4	16.6	16.2
8	502	36.0	14.4	504	34.5	13.0	18.4	17.4
9	500	39.0	16.4	503	37.5	15.4	19.5	18.8
10	498	42.5	18.6	500	42.5	17.6	21.2	21.2
11	502	45.5	20.0	506	44.0	19.8	22.8	22.3
12	502	47.5	20.8	504	47.0	21.2	23.8	23.7
13	502	50.5	22.6	507	49.0	22.4	25.4	24.9
14	498	54.5	24.3	507	54.0	24.0	26.9	27.4
15	498	55.5	25.1	504	54.0	24.4	27.6	27.3
16	485	60.5	28.3	476	60.2	26.0	29.3	28.5
17	494	62.5	30.3	448	62.0	29.0	30.8	27.7

40 HP. 2-PHASE, INDUCTION MOTOR.

E = 500 V.

1	2	3	4	5	6	7	8
Nº	PF_1	PF_2	INPUT W_i	OUTPUT W_o	TOTAL EI	TRUE EFF. $\% = \frac{W_o}{W_i}$	APP. EFF $\% = \frac{W_o}{EI}$
1	.148	.037	2.0	0	21.6	0	0
2	.267	.205	5.5	3.4	22.8	62.0	14.8
3	.464	.376	9.8	6.8	23.7	69.7	28.8
4	.585	.475	13.4	10.2	25.6	76.2	39.8
5	.647	.593	17.2	13.6	27.7	79.0	49.0
6	.735	.622	20.3	16.8	29.8	82.9	56.5
7	.760	.702	24.0	20.1	32.8	84.0	61.2
8	.780	.746	27.4	24.1	35.8	88.0	67.2
9	.845	.820	31.8	26.7	38.3	84.0	67.0
10	.880	.830	36.2	29.8	42.4	82.2	70.0
11	.880	.889	39.8	32.8	45.1	82.2	72.5
12	.875	.890	42.0	36.1	47.5	86.7	76.0
13	.890	.898	45.0	39.1	50.3	87.0	78.0
14	.902	.877	48.3	42.5	54.3	88.0	78.5
15	.910	.892	49.5	45.2	54.9	91.3	82.5
16	.965	.912	54.3	47.8	57.8	88.0	83.0
17	.983		61.1	50.7	58.5	83.0	86.5

40 HP, 2-PHASE, INDUCTION MOTOR.

E = 500V.

1	2	3	4	5	6
No.	∿	% SLIP	R.P.M.	T LBS.	HP
1	61.4	.04	920	0	0
2	61.4	.26	918	5	4.6
3	61.4	.48	917	10	9.2
4	61.4	.65	915	15	13.8
5	61.4	.87	913	20	18.3
6	60.7	.99	901	25	22.6
7	60.7	1.25	899	30	26.9
8	60.7	1.43	897	35	31.4
9	60.7	1.69	895	40	35.8
10	60.2	1.89	885	45	39.8
11	60.0	2.20	880	50	44.0
12	60.0	2.08	881	55	48.5
13	59.7	2.50	874	60	52.4
14	59.5	2.70	878	65	57.0
15	59.5	2.73	867	70	60.7
16	58.5	2.92	853	75	64.1
17	58.5	3.30	850	80	68.0

40 HP, 2-PHASE, INDUCTION MOTOR.

E = 580V.

1	2	3	4	5	6	7	8	9
Nº	E_1	I_1	W_1	E_2	I_2	W_2	E_1I_1	E_2I_2
1	579	25.5	2.1	583	25.0	4	14.8	14.6
2	578	26.5	3.9	583	26.0	2.6	15.3	15.2
3	584	28.0	6.1	592	27.0	4.4	16.4	16.0
4	584	29.0	8.0	591	28.0	6.2	16.9	16.6
5	583	30.5	9.8	591	29.0	7.8	17.8	17.2
6	580	32.5	11.6	589	30.5	9.0	18.8	18.0
7	580	34.2	13.2	587	32.5	11.2	19.8	19.1
8	583	36.5	14.8	587	34.5	12.8	21.3	20.3
9	579	38.5	17.2	584	37.0	15.0	22.2	21.6
10	583	40.5	18.0	587	38.8	16.0	23.6	22.7
11	580	45.5	21.2	582	42.0	18.8	26.4	24.5

40 HP, 2-PHASE, INDUCTION MOTOR.

E = 580 V.

1	2	3	4	5	6	7	8
No.	PF_1	PF_2	INPUT W_i	OUTPUT W_o	TOTAL EI	TRUE EFF. $\% = \frac{W_o}{W_i}$	APP. EFF. $\% = \frac{W_o}{EI}$
1	.141	.027	2.5	0	29.4	0	0
2	.256	.171	6.5	3.4	30.5	52.6	11.2
3	.373	.275	10.5	6.9	32.4	65.5	21.2
4	.470	.374	14.2	10.3	33.5	72.6	30.8
5	.550	.454	17.6	13.6	35.0	77.2	38.8
6	.615	.500	20.6	17.0	36.8	82.8	45.2
7	.667	.587	24.4	20.8	38.9	85.2	53.6
8	.694	.630	27.6	23.4	41.6	84.8	56.0
9	.773	.693	32.2	26.6	43.8	82.6	61.0
10	.760	.705	34.6	29.8	46.3	86.0	64.2
11	.804	.768	40.0	32.1	50.9	80.2	63.2

40 H.P. 2-PHASE, INDUCTION MOTOR.

E = 580V.

1	2	3	4	5	6
No.	∽	% SLIP	R.P.M.	T LBS.	H.P.
1	61.7	.02	923	0	0
2	61.7	.28	922	5	4.6
3	61.7	.48	921	10	9.2
4	61.7	.67	919	15	13.8
5	61.7	.84	917	20	18.3
6	61.3	.98	912	25	22.8
7	61.3	1.22	910	30	27.3
8	60.4	1.41	895	35	31.4
9	60.4	1.66	893	40	35.6
10	59.3	2.00	884	45	39.9
11	58.6	2.14	861	50	43.1

40 H.P. 2-PHASE, INDUCTION MOTOR.

DETERMINATION OF I^2R LOSS, ROTOR BLOCKED.

1	2	3	4
I_1	W_1	I_2	W_2
18.2	.15	18.5	.15
24.0	.24	24.2	.26
30.8	.46	31.0	.45
37.8	.64	37.5	.68
46.3	1.09	46.0	1.11
56.5	1.64	57.0	1.63
61.8	1.95	62.8	2.07
67.3	2.35	68.2	2.50
78.5	3.25	79.7	3.43

40 H.P. 2-PHASE. INDUCTION MOTOR.

DETERMINATION OF HYSTERESIS AND EDDY-CURRENT LOSSES.

1	2	3	4	5	6	7	8	9	10
E_1	I_1	W_1	E_2	I_2	W_2	∽	I^2R LOSS	(3+6)−8	I cos φ
268	18.0	0	268	17.5	1.2	35.1	.275	.93	3.45
344	18.2	0	344	18.0	1.6	46.8	.285	1.32	3.85
392	18.2	0	392	18.0	1.8	53.3	.285	1.52	3.87
440	18.8	0	440	18.5	2.0	58.0	.295	1.71	3.88

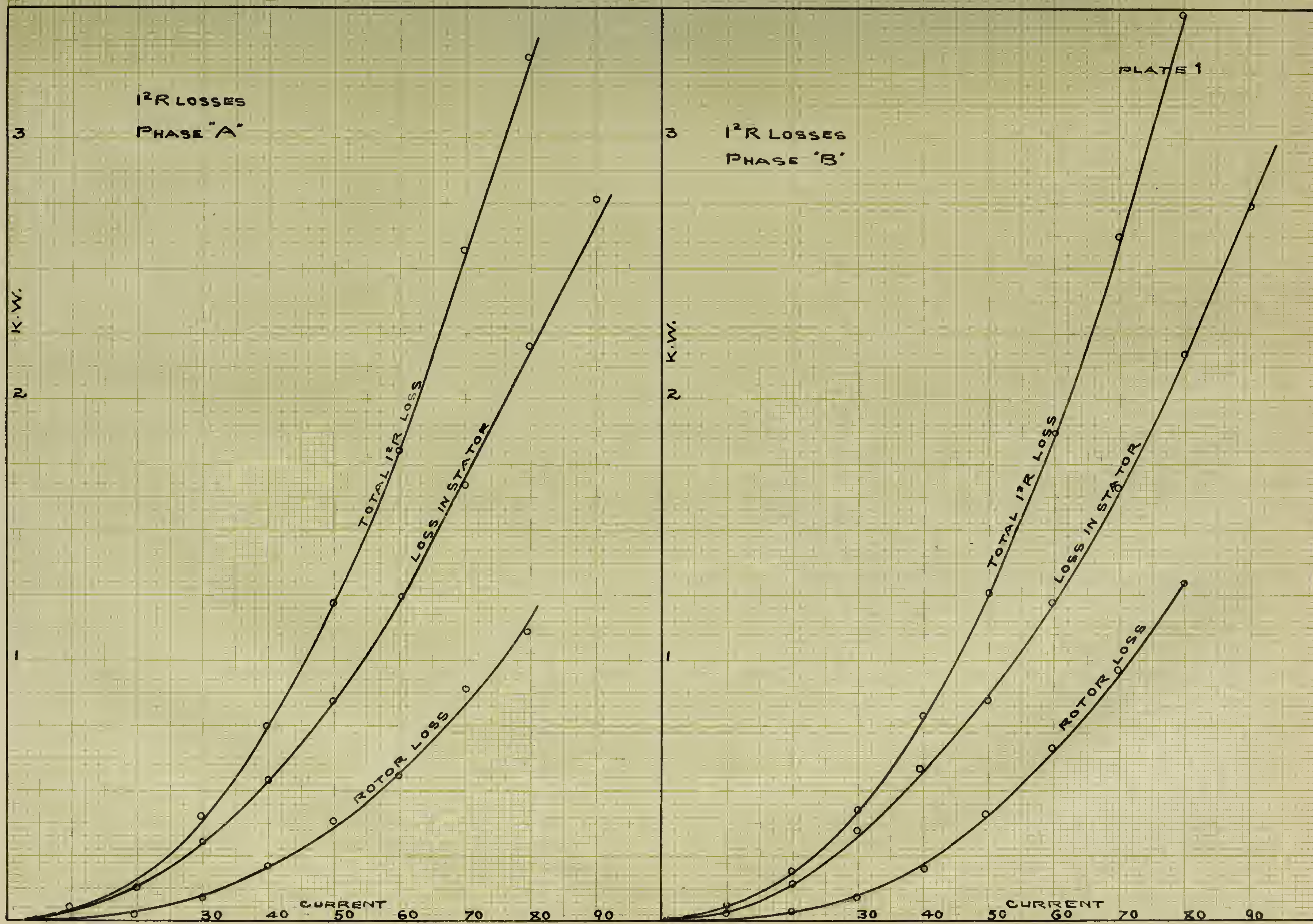


PLATE 1
I²R LOSSES
PHASE "A"
I²R LOSSES
PHASE 'B'
K.W.
3
2
1
CURRENT
30
40
50
60
70
80
90
TOTAL I²R LOSS
LOSS IN STATOR
ROTOR LOSS

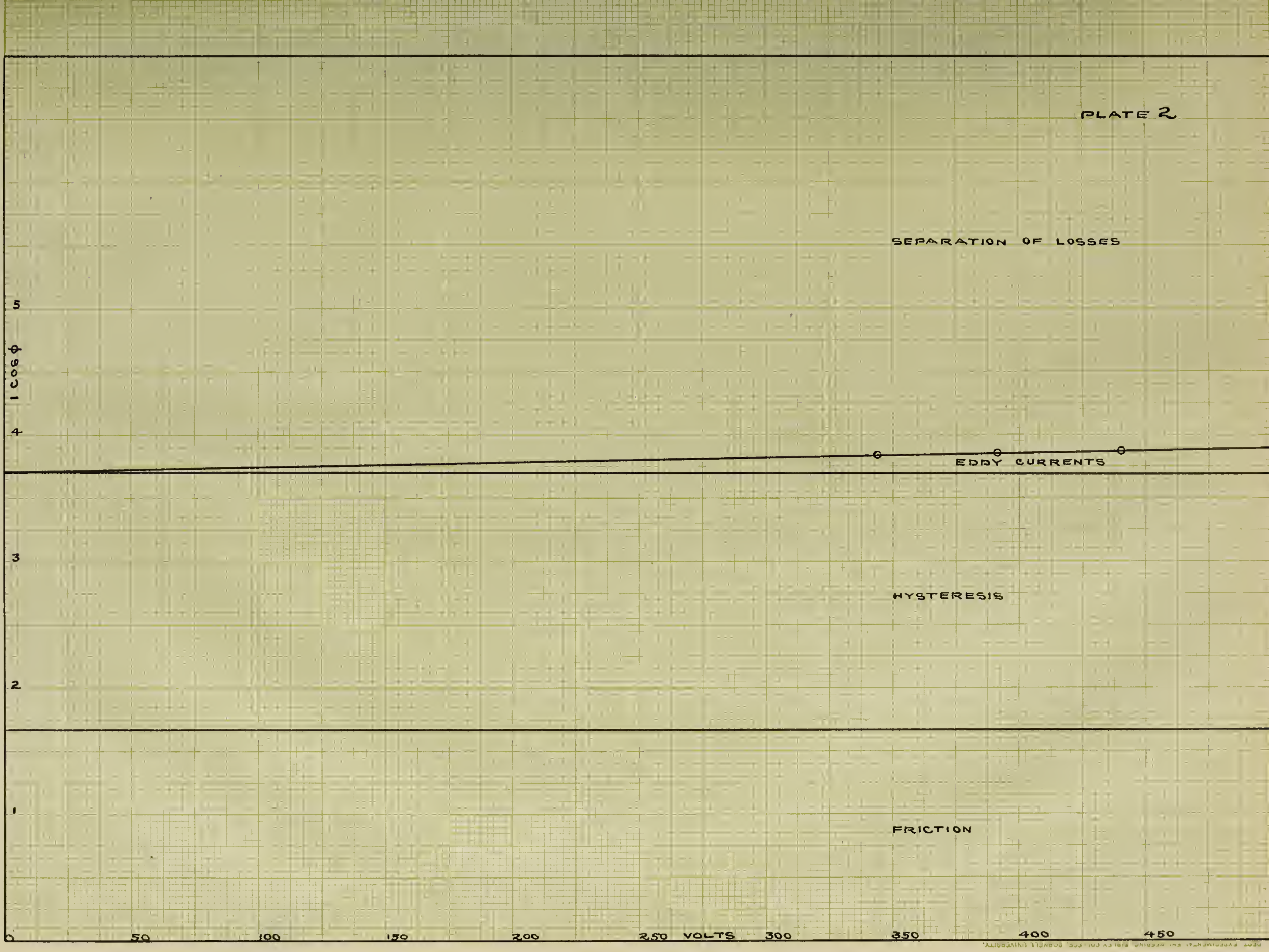


PLATE 2
SEPARATION OF LOSSES
EDDY CURRENTS
HYSTERESIS
FRICTION
I cos φ
5
4
3
2
1
0
50
100
150
200
250
VOLTS
300
350
400
450

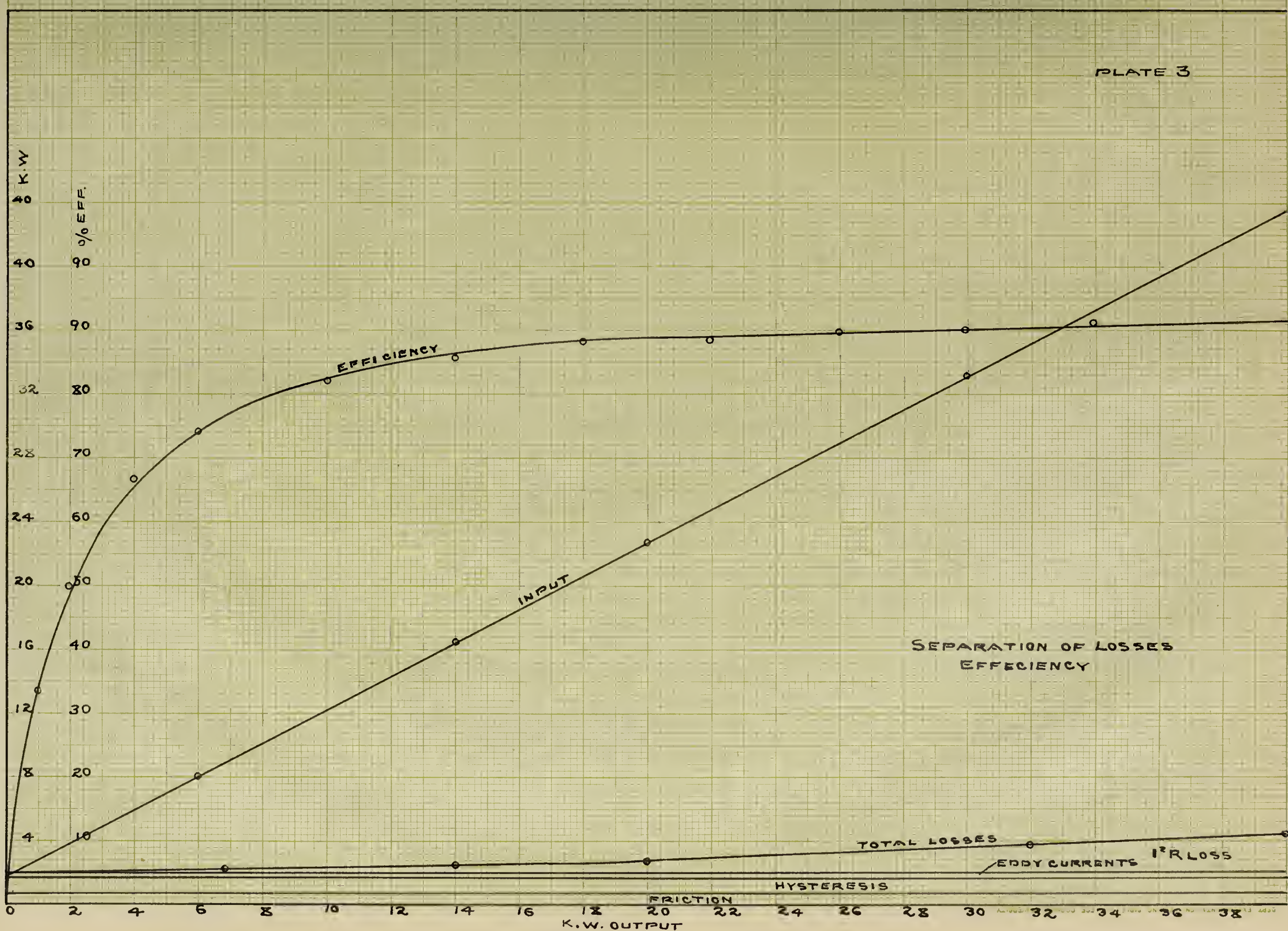


PLATE 3
SEPARATION OF LOSSES
EFFECIENCY
EFFICIENCY
INPUT
TOTAL LOSSES
EDDY CURRENTS
I²R LOSS
HYSTERESIS
FRICTION
K.W
% EFF.
K.W. OUTPUT
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38
40 40 36 32 28 24 20 16 12 8 4
90 90 80 70 60 50 40 30 20 10

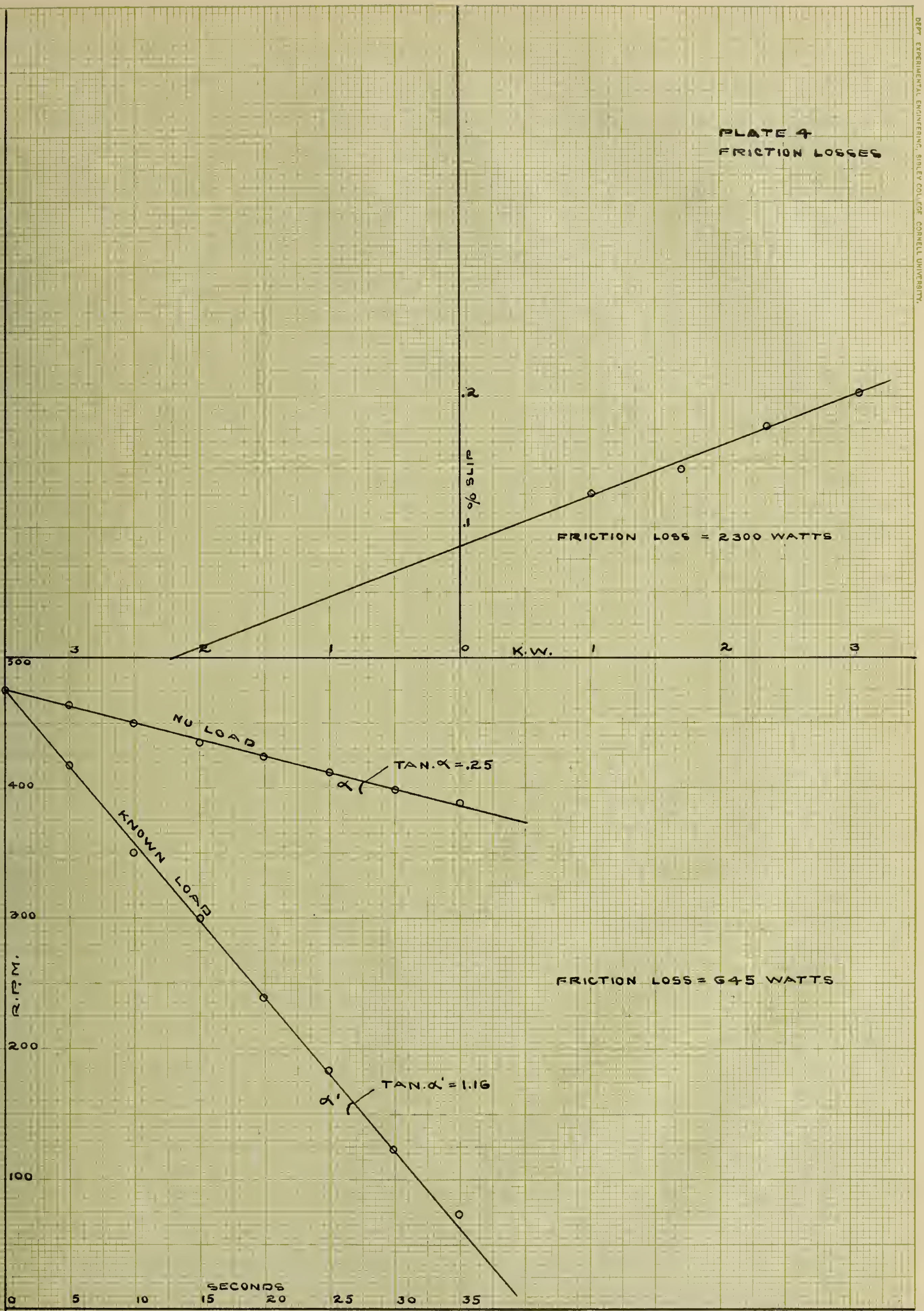


PLATE 4
FRICTION LOSSES
.2
% SLIP
FRICTION LOSS = 2300 WATTS
3
2
1
0
K.W.
1
2
3
500
NO LOAD
TAN. α = .25
α
400
KNOWN LOAD
300
R.P.M.
FRICTION LOSS = 645 WATTS
200
TAN. α' = 1.16
α'
100
SECONDS
0
5
10
15
20
25
30
35

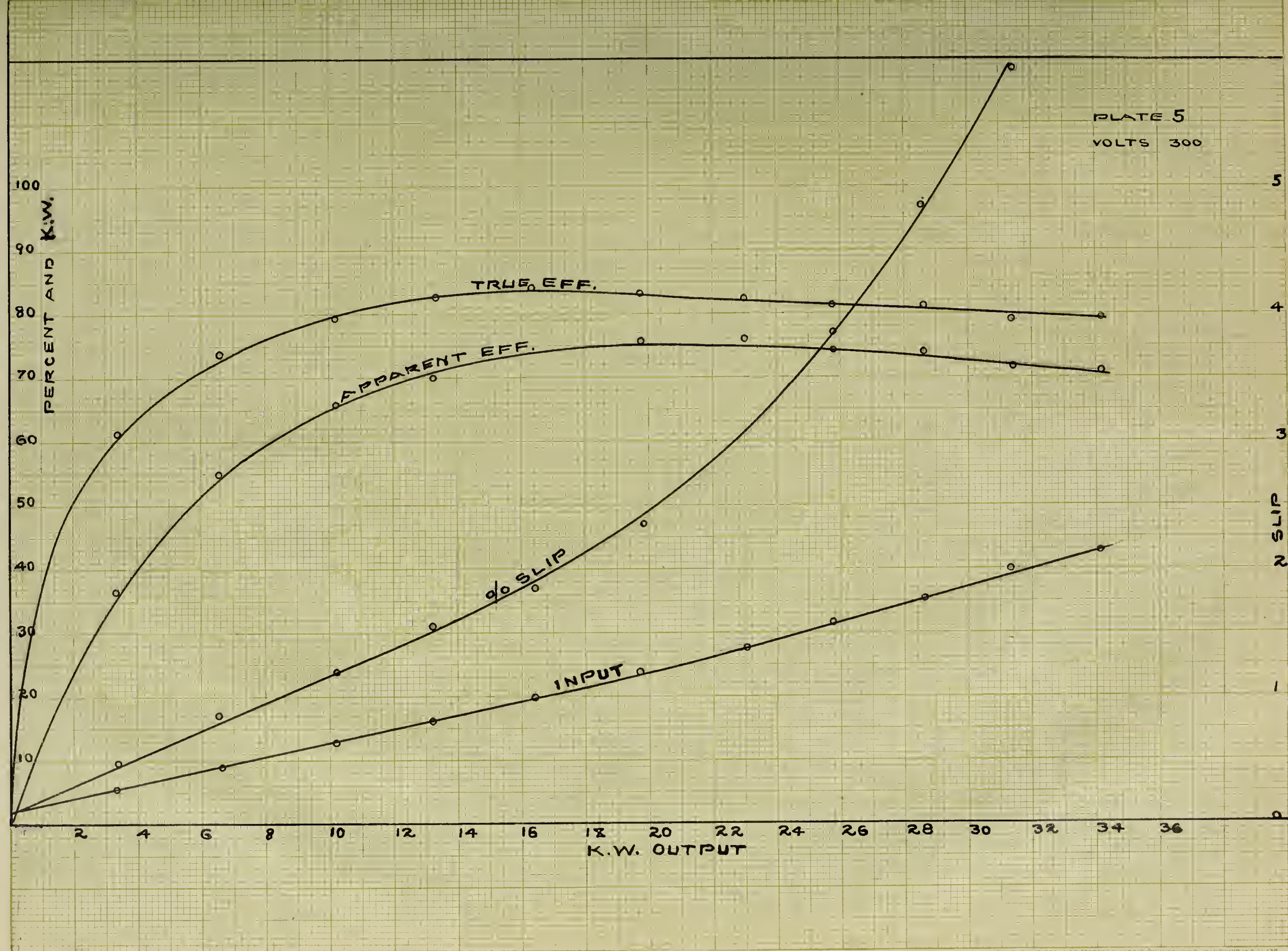


PLATE 5
VOLTS 300
PERCENT AND K.W.
100
90
80
70
60
50
40
30
20
10
5
4
3
% SLIP
2
1
0
TRUE EFF.
APPARENT EFF.
% SLIP
INPUT
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
K.W. OUTPUT
DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY.

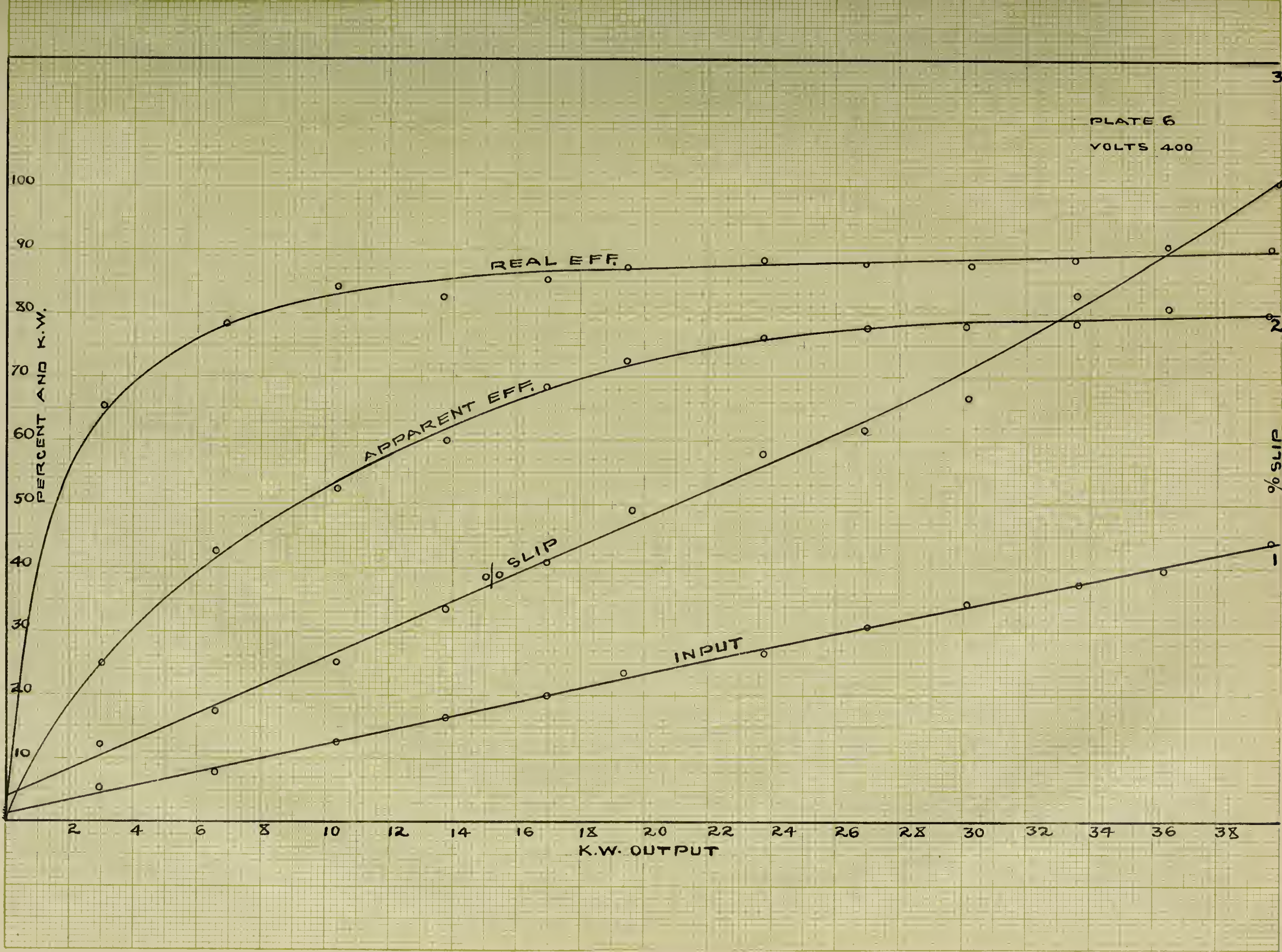


PLATE 6
VOLTS 400
REAL EFF.
APPARENT EFF.
% SLIP
INPUT
% SLIP
PERCENT AND K.W.
K.W. OUTPUT
100
90
80
70
60
50
40
30
20
10
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
1
2
3
DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY.

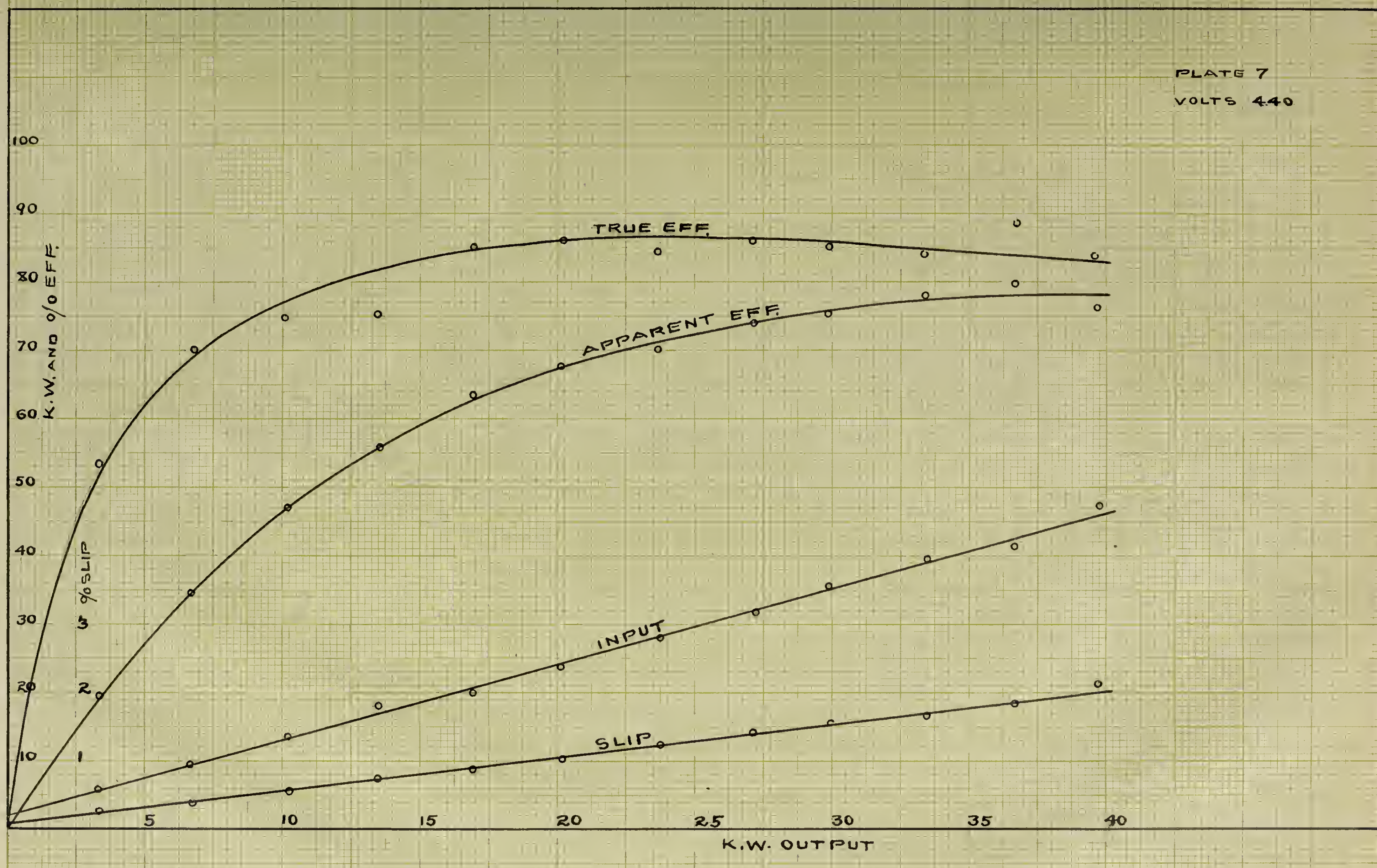


PLATE 7
VOLTS 440
TRUE EFF.
APPARENT EFF.
INPUT
SLIP
K.W. AND % EFF.
% SLIP
K.W. OUTPUT
100
90
80
70
60
50
40
30
20
10
3
2
1
5
10
15
20
25
30
35
40

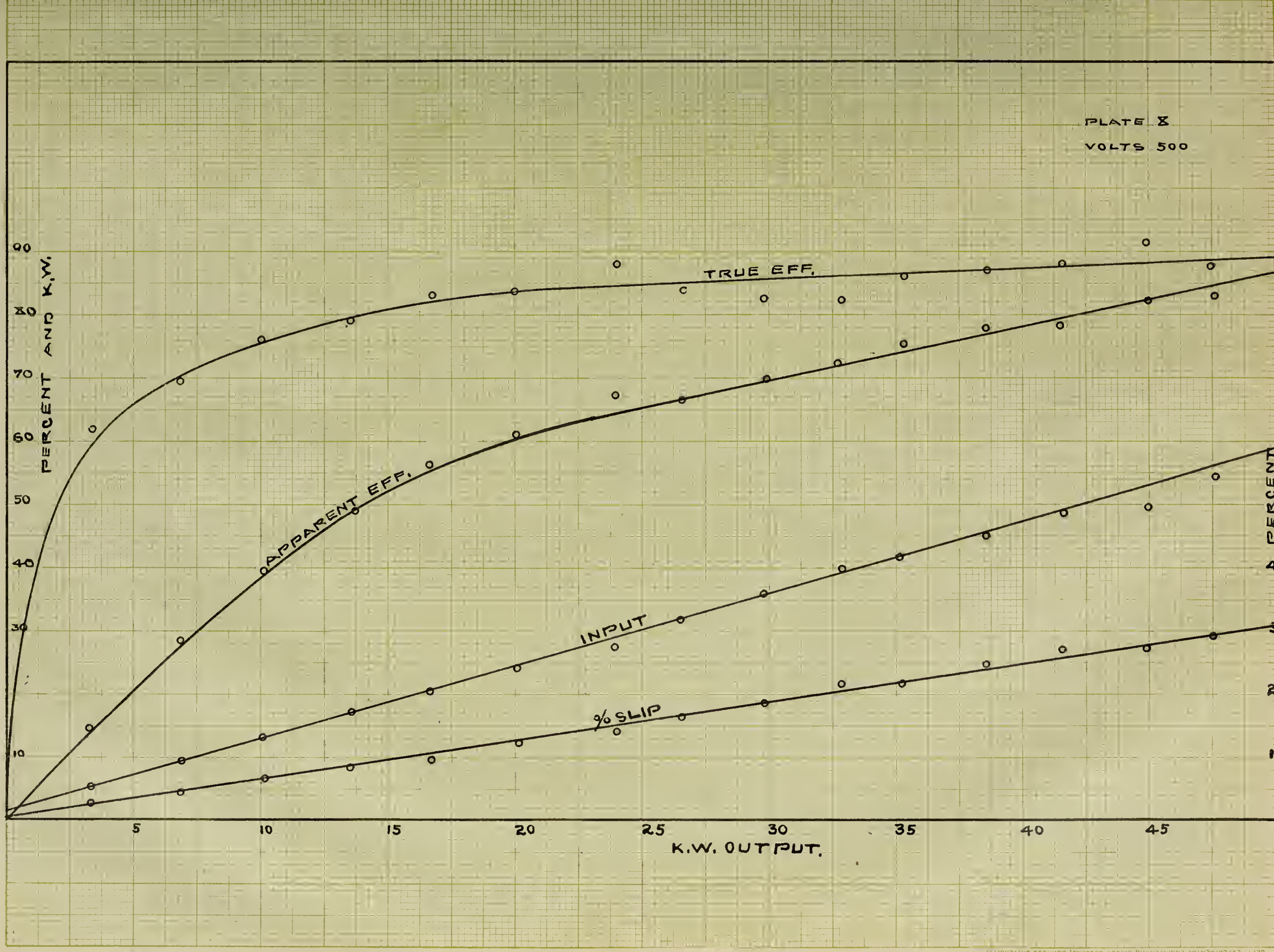


PLATE X
VOLTS 500
TRUE EFF.
APPARENT EFF.
INPUT
% SLIP
PERCENT AND K.W.
PERCENT
K.W. OUTPUT.
90
80
70
60
50
40
30
10
1
2
3
4
5
10
15
20
25
30
35
40
45
50
DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY.

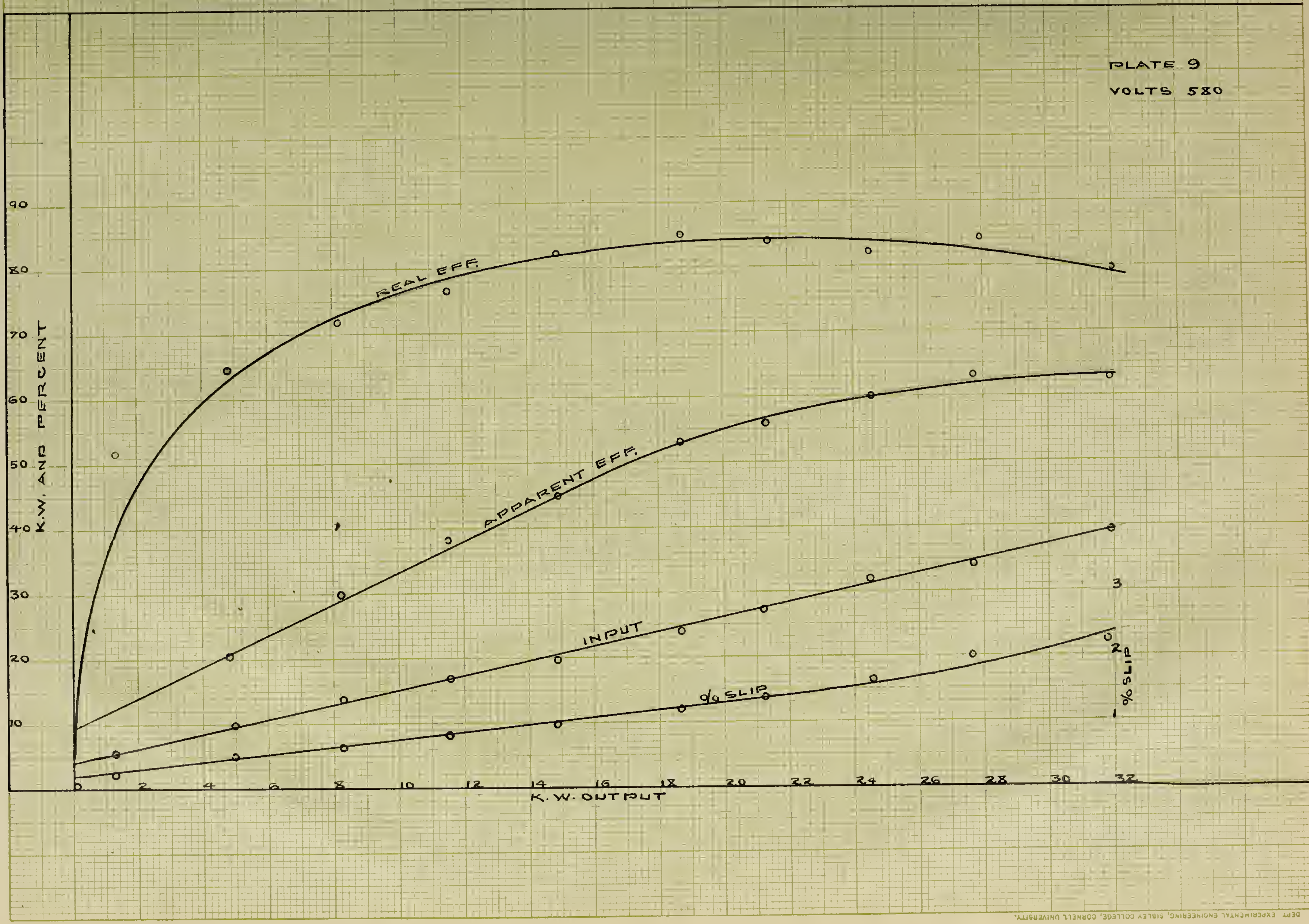


PLATE 9
VOLTS 580
REAL EFF.
APPARENT EFF.
INPUT
% SLIP
K.W. AND PERCENT
K.W. OUTPUT
10
20
30
40
50
60
70
80
90
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
1
2
3

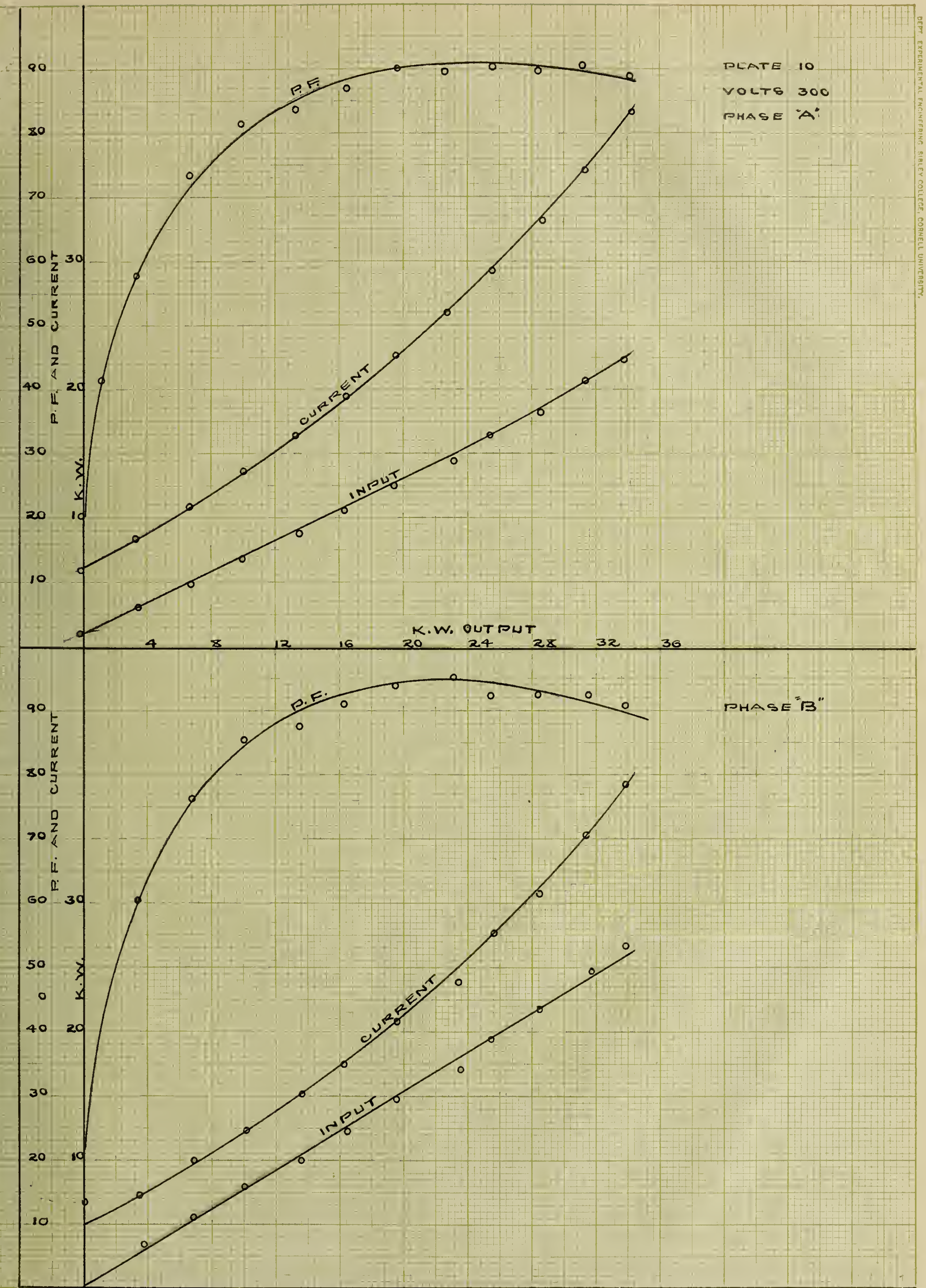


PLATE 10
VOLTS 300
PHASE "A"
PHASE "B"
P.F.
CURRENT
INPUT
K.W. OUTPUT
P.F. AND CURRENT
K.W.
DEPT. EXPERIMENTAL ENGINEERING SIBLEY COLLEGE, CORNELL UNIVERSITY.

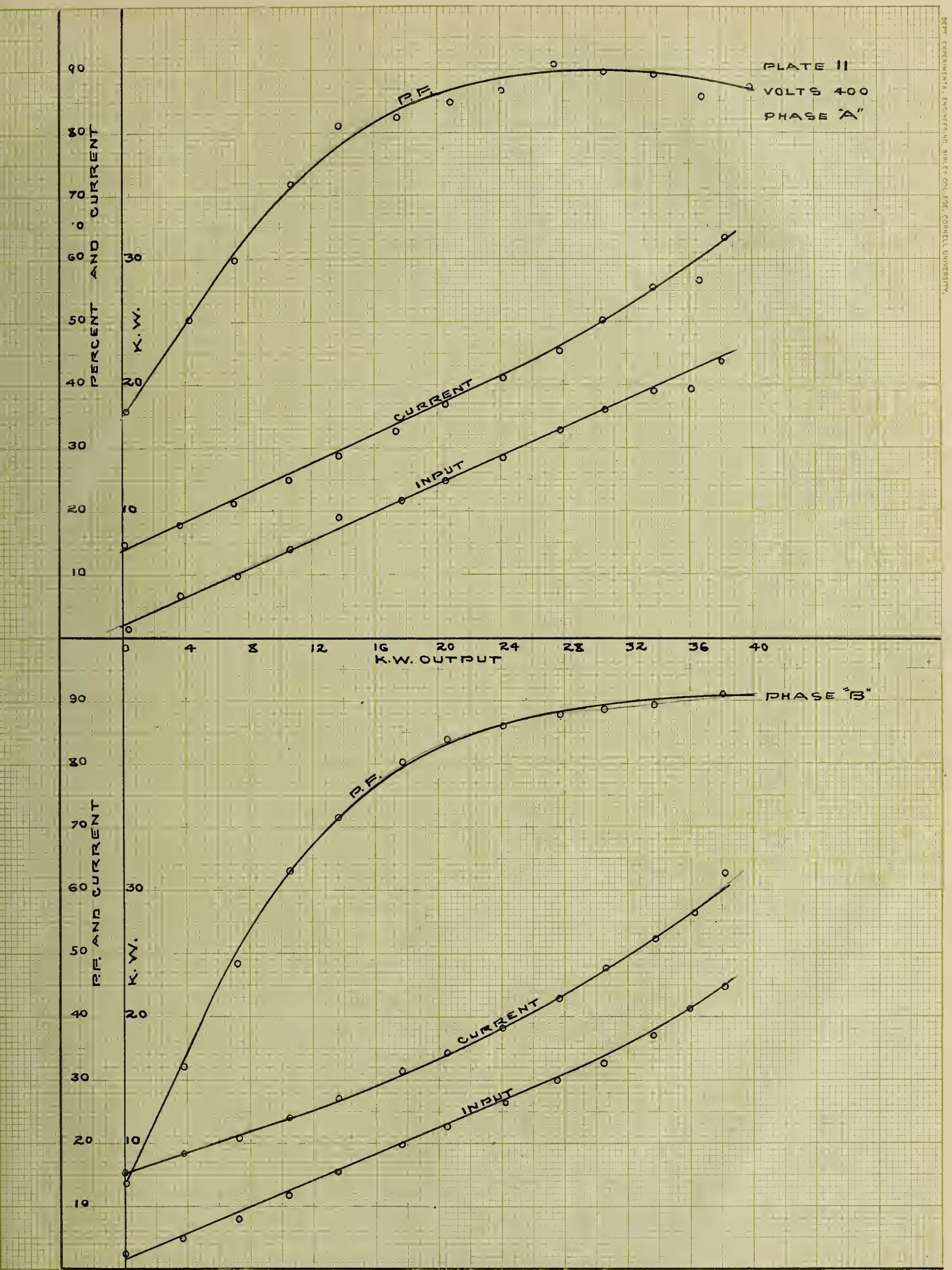


PLATE II
VOLTS 400
PHASE "A"
PERCENT AND CURRENT
K.W.
P.F.
CURRENT
INPUT
90
80
70
60
50
40
30
20
10
30
20
10
0
4
8
12
16
20
24
28
32
36
40
K.W. OUTPUT
PHASE "B"
P.F. AND CURRENT
K.W.
P.F.
CURRENT
INPUT
90
80
70
60
50
40
30
20
10
30
20
10
DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COL. ENG. CORNELL UNIVERSITY.

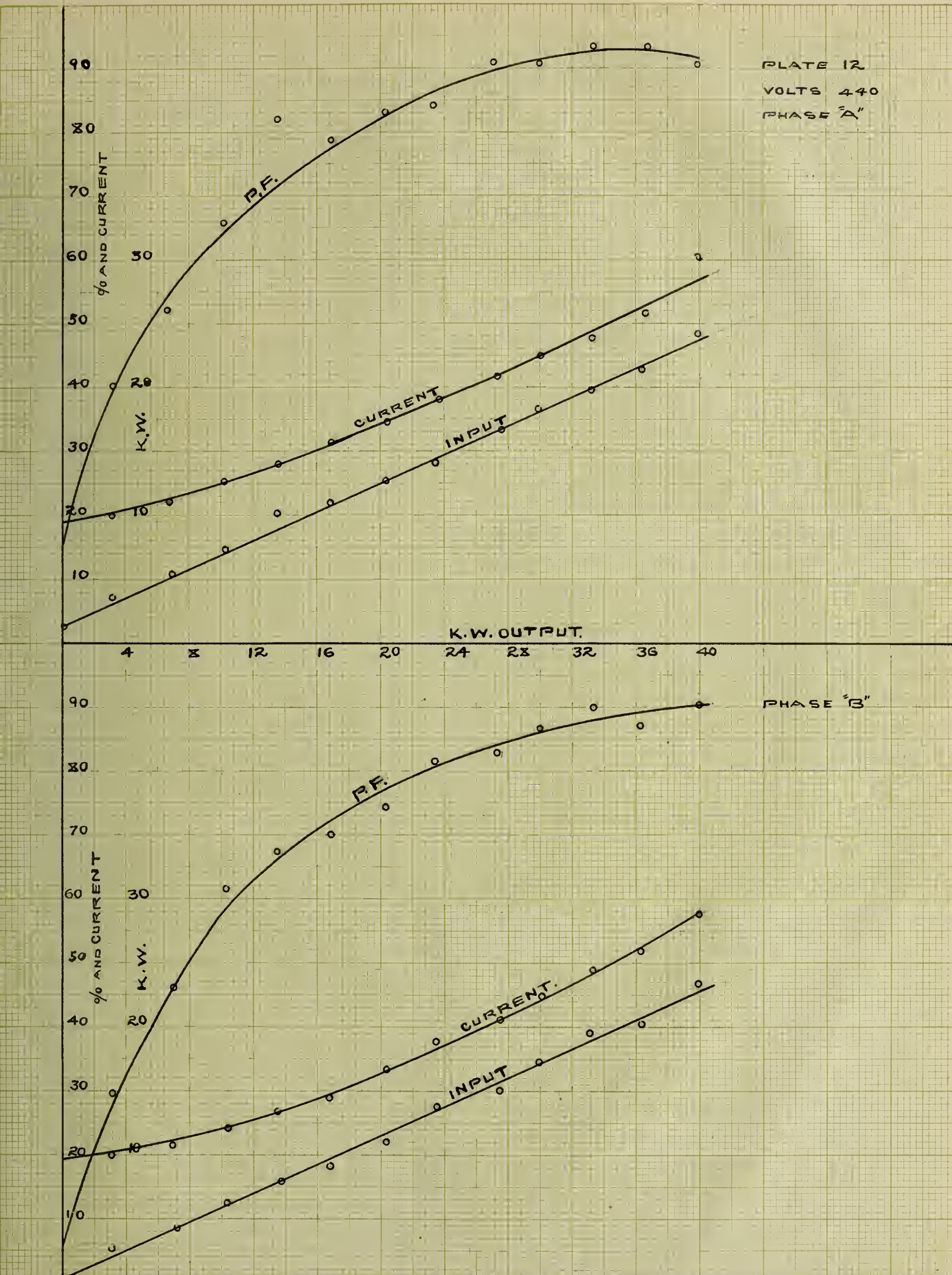


PLATE 12
VOLTS 440
PHASE "A"
P.F.
CURRENT
INPUT
% AND CURRENT
K.W.
K.W. OUTPUT.
4 8 12 16 20 24 28 32 36 40
10 20 30 40 50 60 70 80 90
10 20 30
PHASE "B"
DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY.

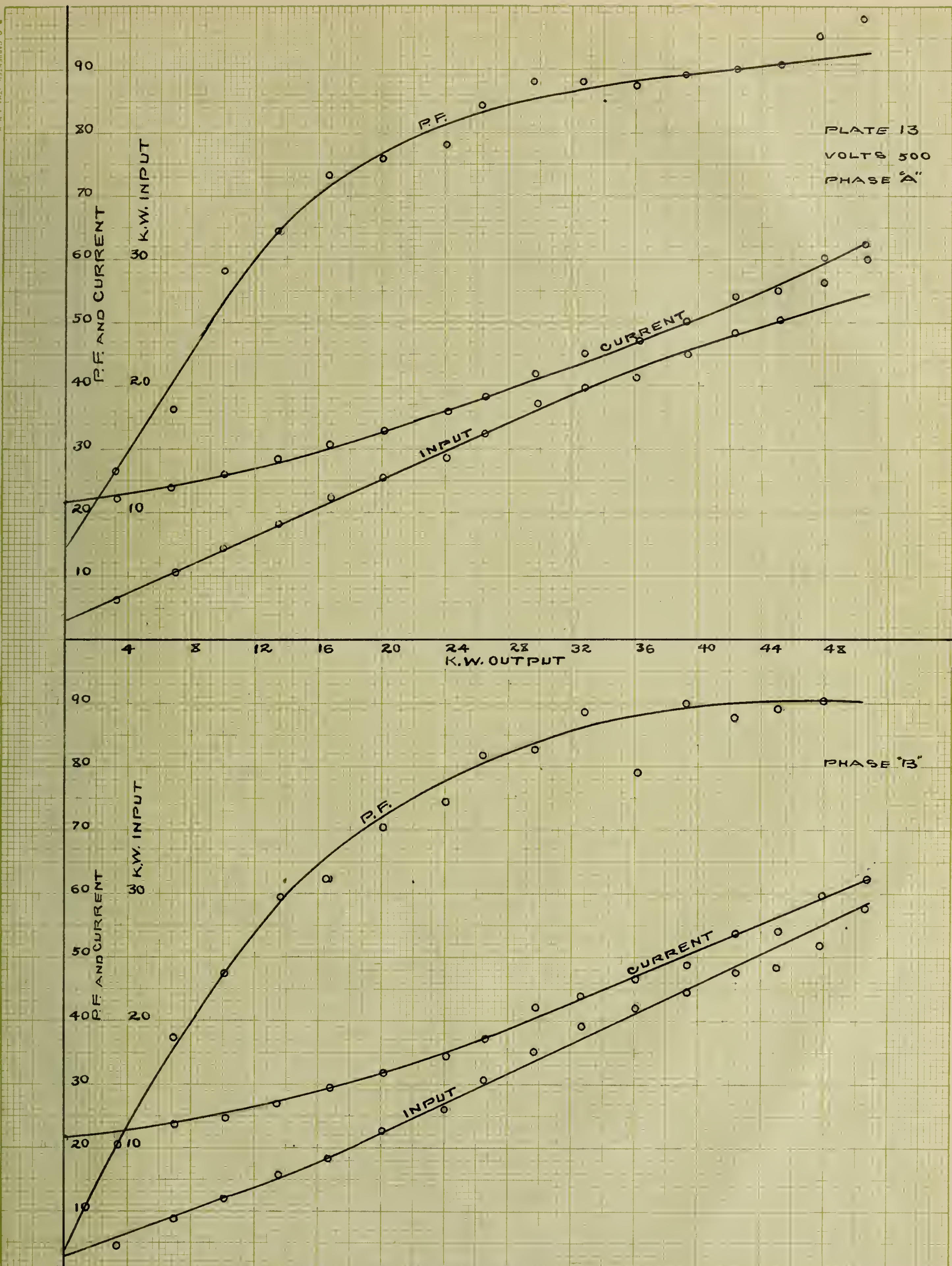


PLATE 13
VOLTS 500
PHASE "A"
P.F.
CURRENT
INPUT
P.F. AND CURRENT
K.W. INPUT
90
80
70
60
50
40
30
20
10
30
20
10
4 8 12 16 20 24 28 32 36 40 44 48
K.W. OUTPUT
PHASE "B"
P.F.
CURRENT
INPUT
P.F. AND CURRENT
K.W. INPUT
90
80
70
60
50
40
30
20
10
30
20
10
DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY.

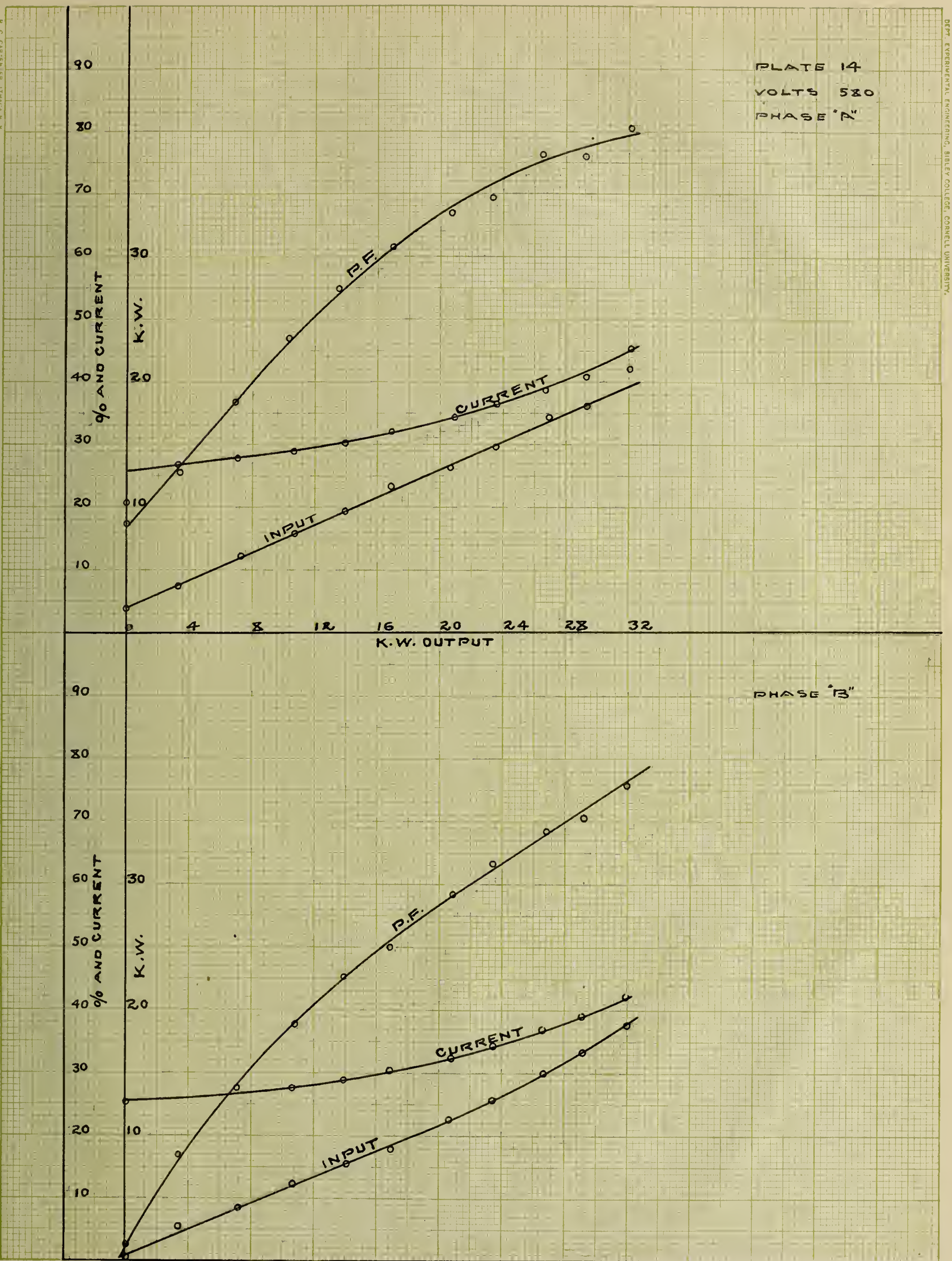


PLATE 14
VOLTS 580
PHASE "A"
P.F.
CURRENT
INPUT
% AND CURRENT
K.W.
K.W. OUTPUT
0
4
8
12
16
20
24
28
32
10
20
30
40
50
60
70
80
90
PHASE "B"
DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY.

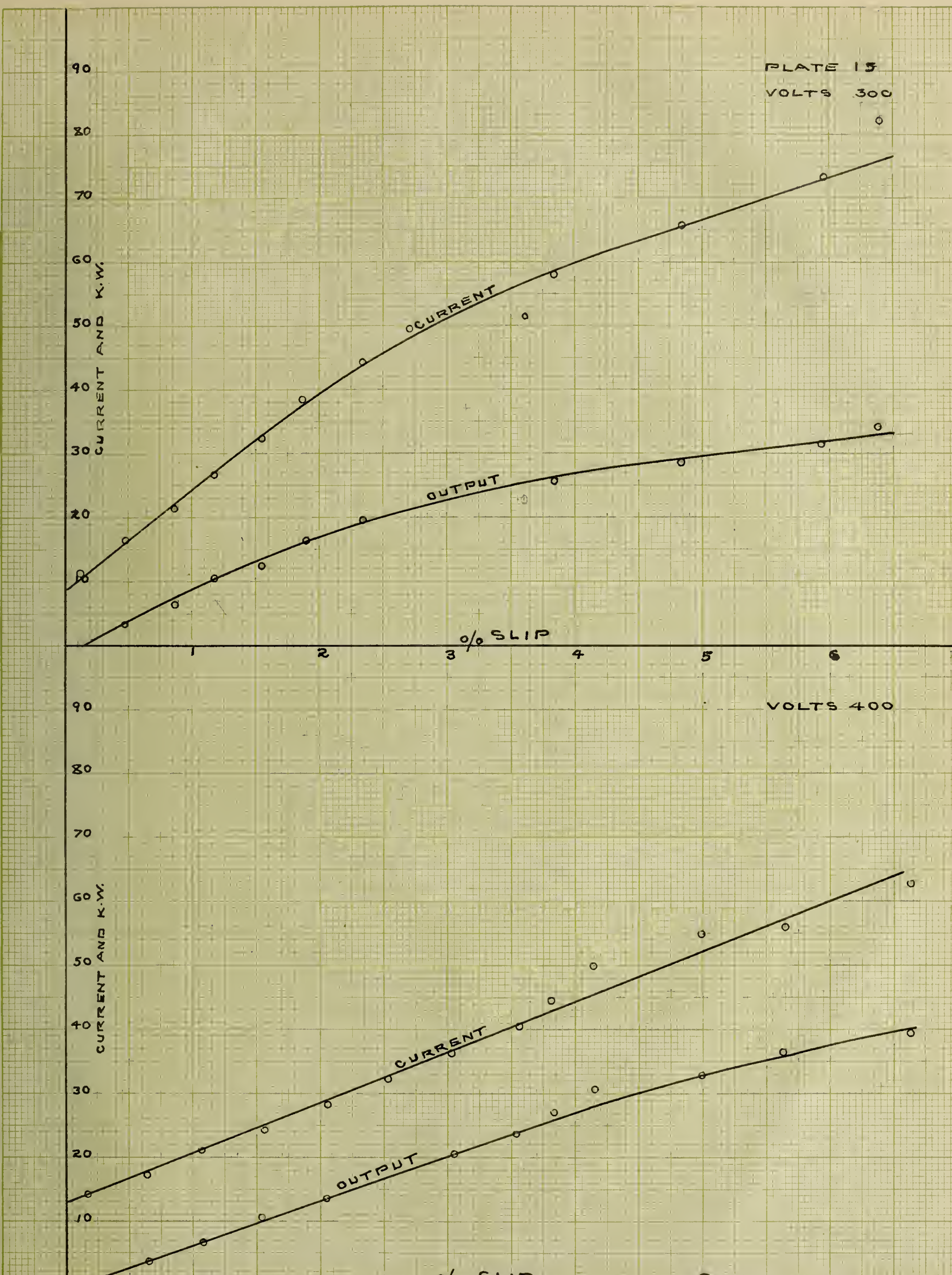


PLATE 15
VOLTS 300
CURRENT
OUTPUT
CURRENT AND K.W.
% SLIP
VOLTS 400
CURRENT
OUTPUT
CURRENT AND K.W.
% SLIP

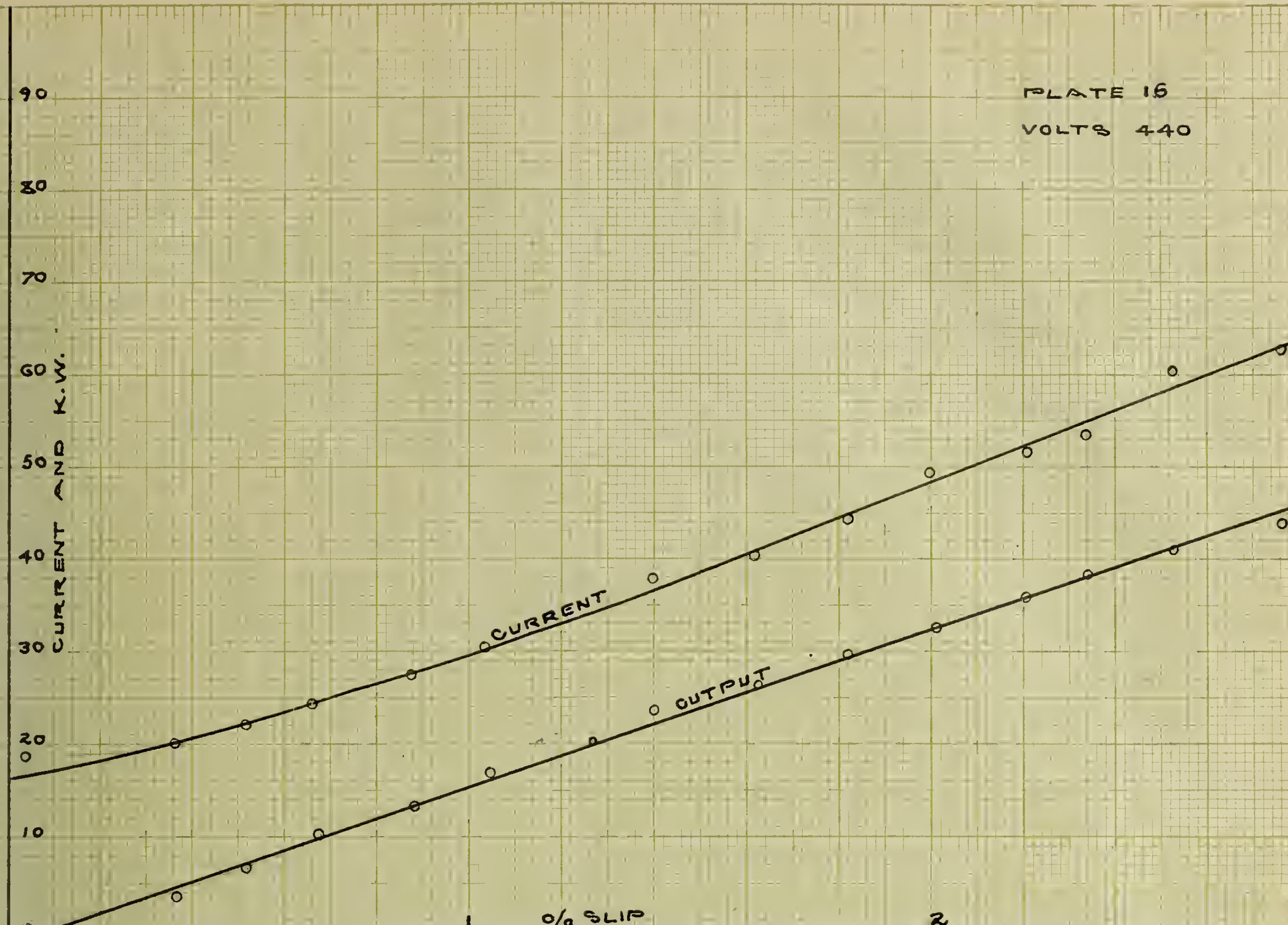
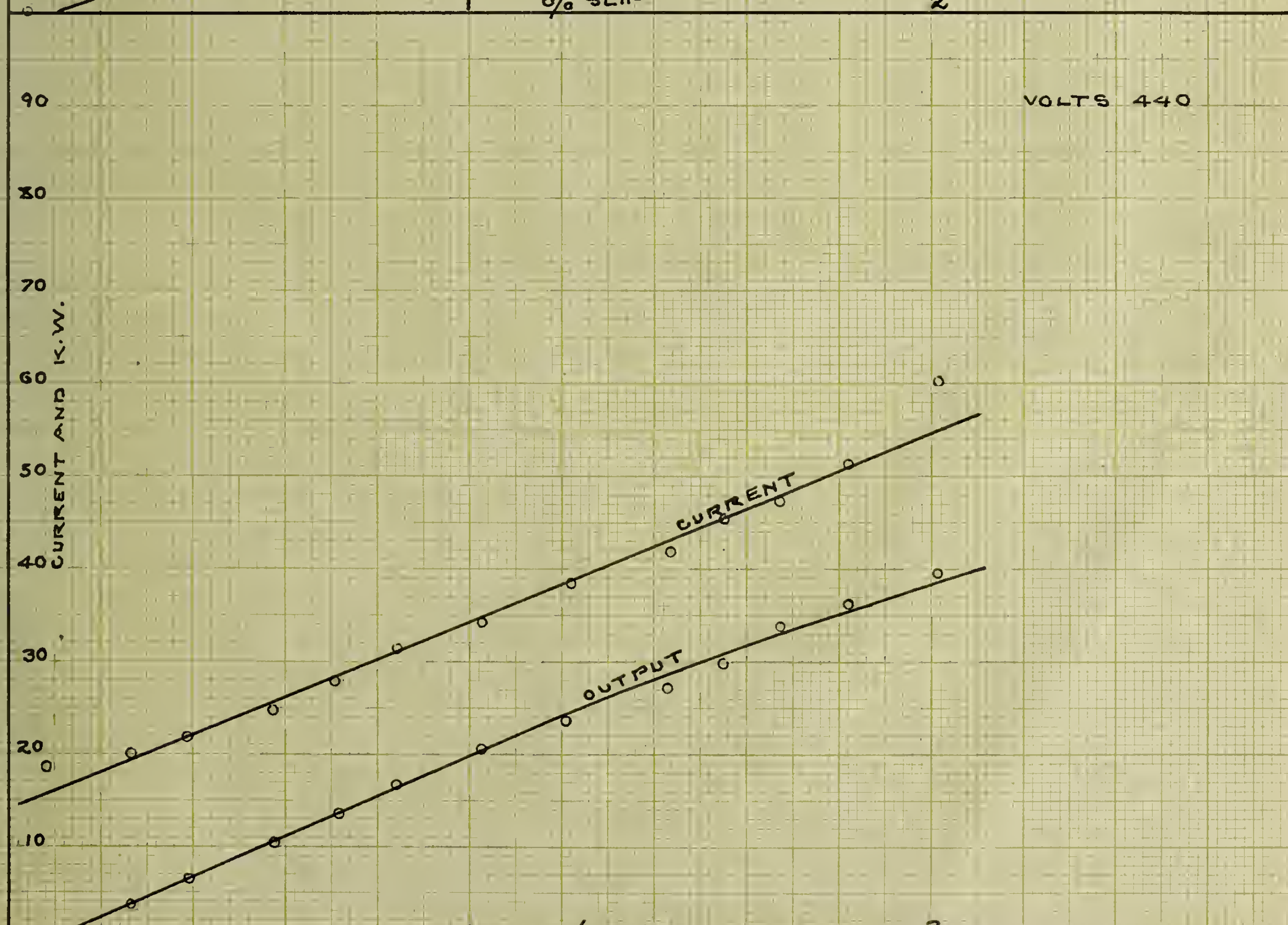


PLATE 16
VOLTS 440
CURRENT AND K.W.
90
80
70
60
50
40
30
20
10
CURRENT
OUTPUT
1
% SLIP
2


VOLTS 440
CURRENT AND K.W.
90
80
70
60
50
40
30
20
10
CURRENT
OUTPUT
1
% SLIP
2

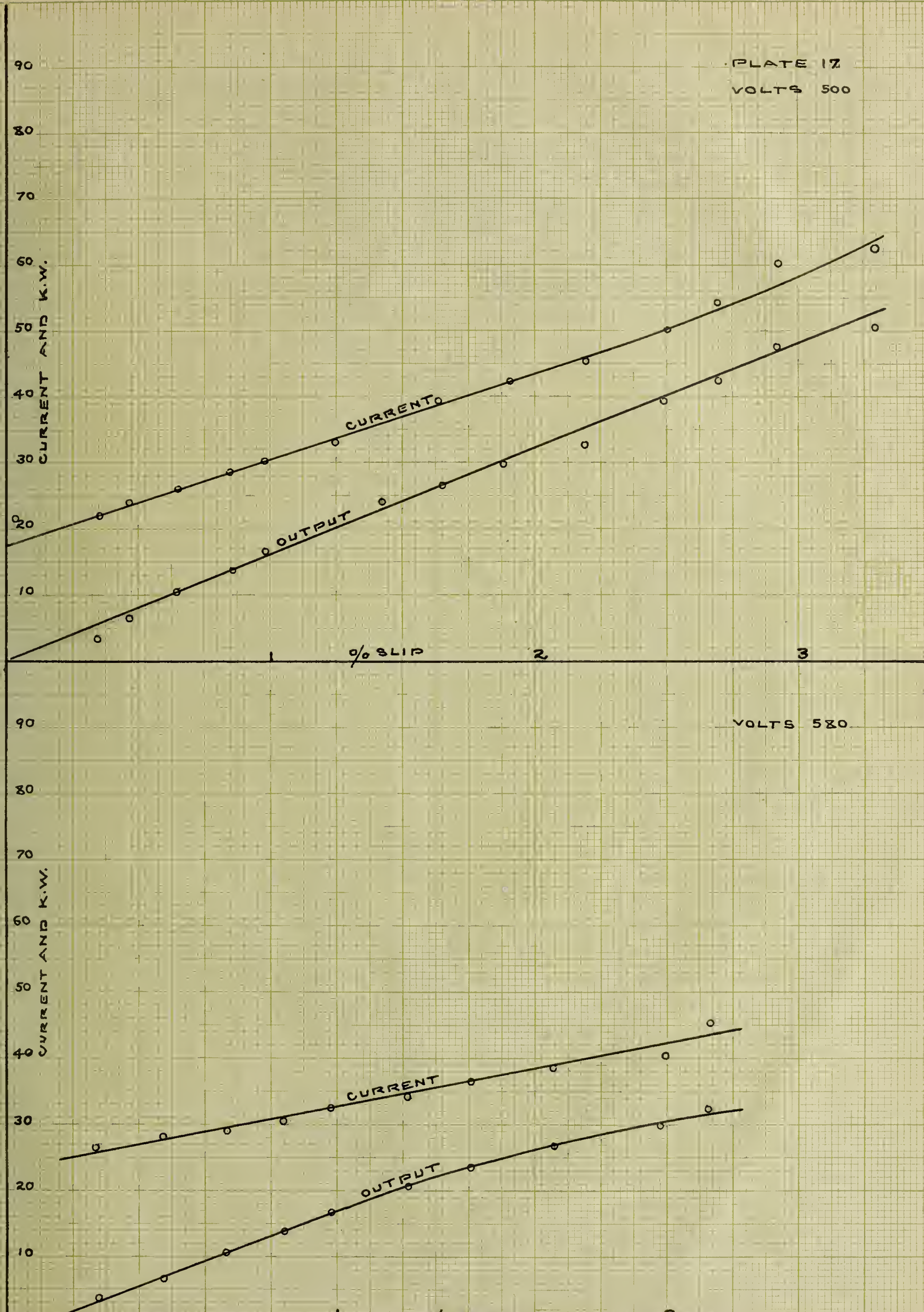
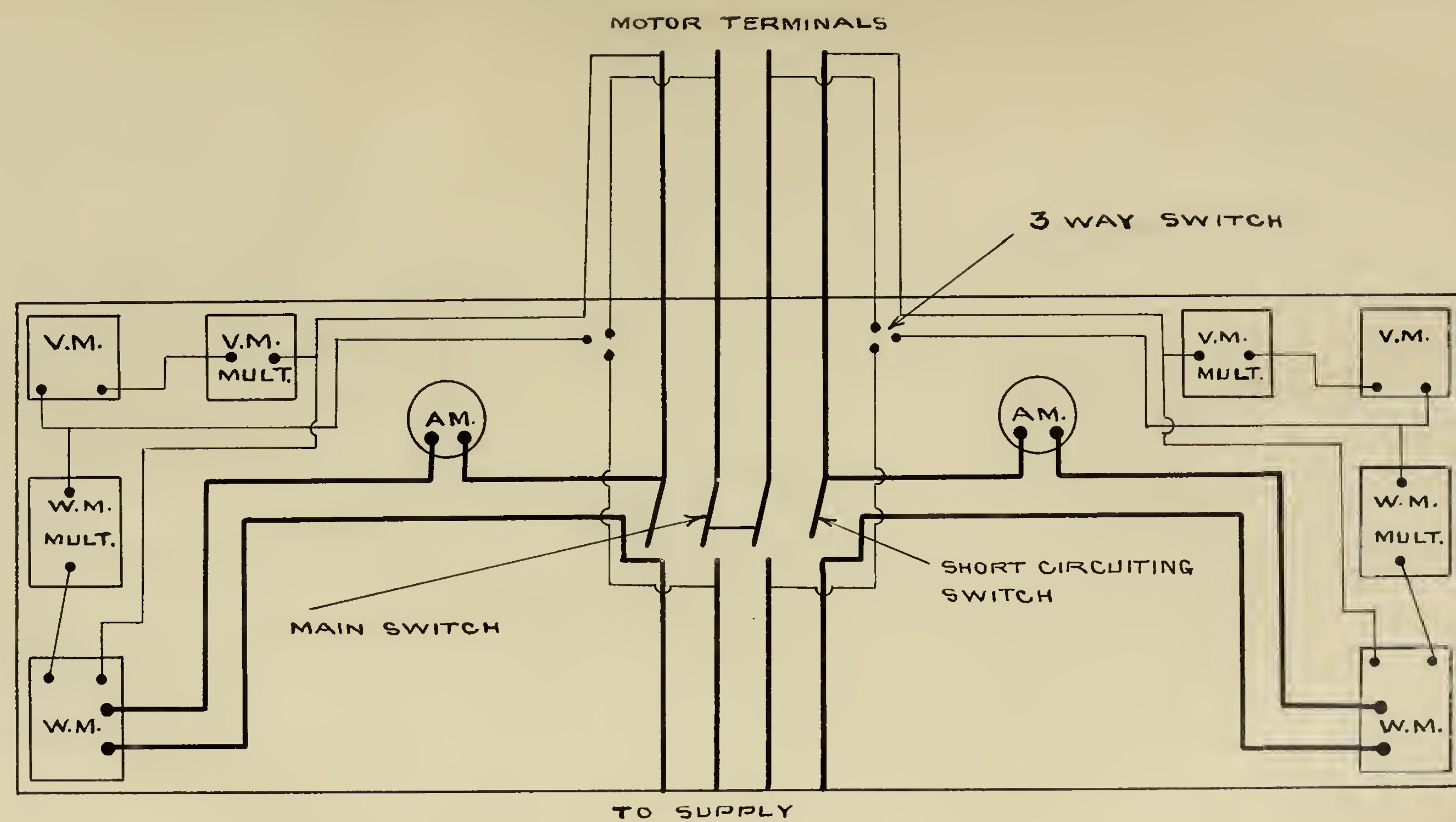


PLATE 17
VOLTS 500
CURRENT AND K.W.
CURRENT
OUTPUT
% SLIP
VOLTS 580
CURRENT AND K.W.
CURRENT
OUTPUT
% SLIP

PLATE No. 18



WIRING DIAGRAM
FOR
TESTING TABLE