STUDY OF 20 K. W. MOTOR GEN. SET.

BY

JAMES BEN. WHITE

A THESIS SUBMITTED FOR THE DEGREE

OF

BACHELOR OF SCIENCE

IN

ELECTRICAL ENGINEERING

COURSE

University of Tennessee

1 9 2 7 .

---oOo---

CONTENTS

PART I

		Curve.	Fig.	Page.
A.	CIRCLE DIAGRAM			
	1. Method			2
	2. Tabulated Results		I.	
	3. The Diagram	E.		
	4. Curves	D.		

PART II

B.	HEAT RUN			
	1. Method			10
	2. Tabulation		IV.	
	3. Curve	A.		
	4.			
C.	RUNNING TEST			
	1. Method			
	2. Tables		II.	
	3. Curves	C.		
D.	EFFICIENCY CHECK			
	1. Tables		III.	
	2. Curves	B.		

THE STUDY OF A 20 K. W. MOTOR GEN. SET.

30 H. P. Induction Motor G. E. 3 phase.

20 K. W. Generator Westinghouse D. C.

This thesis is not an exploration of the unknown but merely a study of an apparatus as a means of gaining a knowledge of the particular machines and of obtaining for the performer of this thesis a better knowledge of Motor Generator sets in general. The tests were run during the third quarter of the 1926-27 terms of school, upon the Motor Generator set of the Electrical Laboratory, used for the main D. C. Source, and is of course applicable to the apparatus, only as installed at that time.

Data were first obtained for a circle diagram from which several elements were calculated and then direct tests were run as a check, where ever possible.

The information from data and calculations include the following.

(1) Results and calculated values from the circle obtained.

(2) Heating effect on Motor (direct test) (Curve A.)

(3) Efficiency, regulation, power factor slips, and input for varying loads on the generator. (Curve C).

(4) Curves for circle diagram (data and calculated values from the circle diagram) (Curve D.)

(6) The circle diagram itself as obtained from data at no load and lock load conditions.

The first item of the tests that will be treated is that of the circle diagram calculations from data as recorded later. But first we must remember that the reason a circle diagram may be constructed to represent the behavior of the motor is due to the fact that the Induction Motor aside from exciting current is equivalent, with varying load, to a circuit having constant reactance and variable resistance.

This may be shown by an examination of the following equation:

$$I_2 = \frac{s\mathcal{E}_2}{\sqrt{r^2 + s_2 x_2^2}} = \frac{\mathcal{E}_2}{\sqrt{\frac{r^2}{s^2} + x_2^2}}$$

For a variable load the locus of (1) 2 is a circle and the complete performance of the polyphase induction motor can be derived from the circle diagram.

Two sets of readings are required. (Magnusson's Alternating Currents).

I. No load (running idle) corresponding to open secondary on a transformer.

II. Rotar locked, corresponding to short circuit condition for a transformer.

At no load, the rated voltage is applied to terminals and readings taken of current and power input. The ammeter gives the exciting current m I and the Wattmeter the core losses windage and friction. The losses due to windage and friction are small, so the power indicated by the Wattmeter

may be considered as due to conductance in the exciting circuit as shown in Magnusson's Alternating Currents (Fig. 239 page 200) the exciting current has component in time phase (power component) and time quadrature (magnetizing current with the voltage and their magnitudes are determined by amps, volts and watts taken at no load.

ROTOR LOCKED

For the second set of readings the rotor is clamped and sufficient voltage applied to give about twice the full-load current in the primary (In this particular test about (1.5 times) readings are taken to obtain volts, amps, and watts and power factor.

These readings are converted to full load voltage (222.5 volts in this test).

With these two points it is then possible to construct a circle diagram and calculate or determine the following values.

P. M. = I_1 Exciting Current in Primary.

P. C. = $I 2_1$ Current in Secondary.

M. C. = m I Exciting Current.

P. L. = Input in watts.

Mn = Core loss, wind, and friction.

H. K. = Primary copper losses.

F. H. = Secondary copper losses.

$$\text{power factor} = \frac{PL}{PM}$$

$$\text{Slip} = \frac{FH}{PH}$$

At no load as running free from shafting the following data and results were obtained.

PHASE	E	I	WATTS = W	COS θ
A	223	1.25 x 20 = 25	-2100	
B	222	1.00 x 20 = 20	3520	
Av.	222.5	22.5	W_1+W_2 = 1420	
			W_1-W_2 = 5620	.154

$$\cos\theta = \frac{1420}{\sqrt{3} \times 222.5 \times 22.6} = .163$$

or

$$\cos = \text{Cos (tan-1)} \frac{\sqrt{3} \times 562}{142} = .145$$

Mean Value = .154 $\sin\theta$ = .988

Core losses windage and friction = input when idling.

Core losses windage and friction = 1420 watts.

Power Component of Current = 22.5 x .154 = 3.46 amps.

Magnetizing " " " = 22.5 x .988 = 22.2 amps.

- -

ROTOR LOCKED. These readings were obtained at a low voltage and must be converted to common voltage after power factor has been determined.

PHASE	E	I (amps)	W	COS θ
A	42	4.33 x 20 = 86.6	3400	Mean
B	42	4.60 x 20 = 92.0	550	Value
Av.	42	= 89.2	$W_1-W_2 = \overline{3950}$	
			$W_1-W_2 = 2850$	.617

$$\text{COS } \theta = \frac{3950}{\sqrt{3} \times 42 \times 89.5} = \frac{3950}{3950} = .61$$

Check Cos θ = Cos $\left(\tan^{-1} \sqrt{3} \times \frac{2850}{3950}\right)$ = .61

and a mean value of .617 is taken.

Note. (check formula is $\tan \theta = \sqrt{3} \frac{(W_1 - W_2)}{(W_1 + W_2)}$

But reduced to 222.5 volts the readings become the following for current.

PHASE	E	I	W	COS θ
A & B				.617
Av.	222.5	472	$W_1 - W_2 = 21,200$	sin θ = .787

Assuming that current is proportional to voltage

Power Component of Current = 472 x .617 = 291 amps.

Magnetizing Component of Current = 472 x .787 = 370 amps.

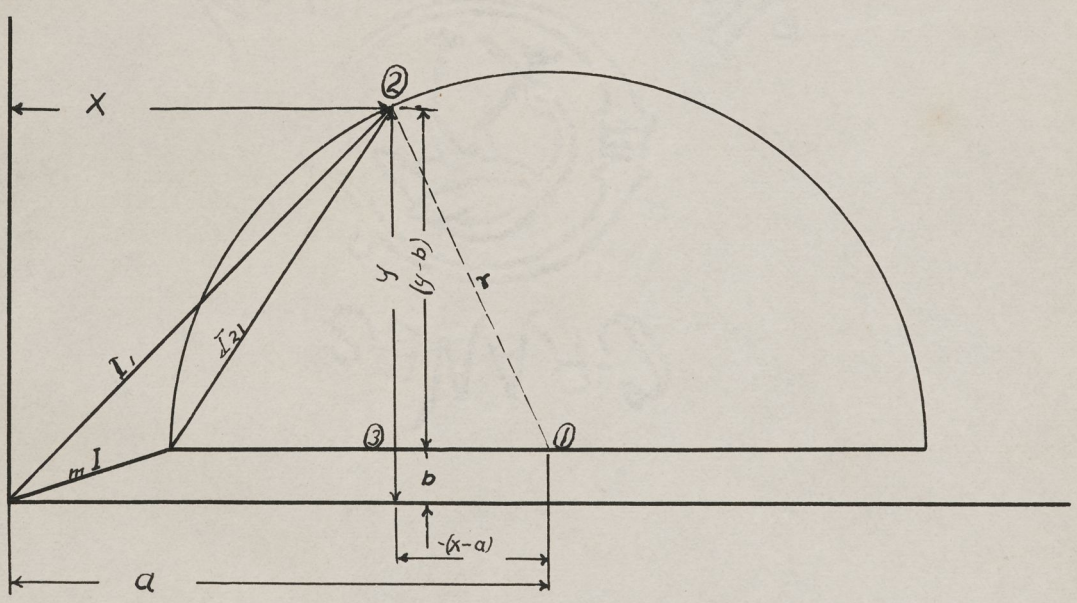
With these data a circle diagram is drawn Rectangular Co-ordinates locating two points on the circle and the diameter being above the x axis by a distance equal to the core losses windage and frictions at no load = 1420 Watts or rather

the working component of the current = 22.2 amps.

Since this circle diagram is on a small scale it becomes necessary, for accuracy, to develop an equation for this circle in terms of radius co-ordinates of center, and co-ordinates of any point on the circumference (x and y).

The Method of Calculation is as follows:

First a general drawing is made see next page, showing all notations and values as they will be used in the testing together with co-ordinates of center of circle.



In the right triangle (1) (2) (3)

$$(x-a)2 - (y-b)2 = r2 \quad \text{(gen eq. circle)}$$

and solving for 2 points (no load
(lock load

sinnul tancously we get.

$$(22.2 - a)2 = (370-a)^2 + (291-3.46)^2 = (22.9-a)^2$$

from which a = 316 and r = a - 22.2 = 284 ampere units.

and in the gen. Equation above.

$$\pm (x-a) = \sqrt{r^2-(y-b)^2} \qquad \text{or } x = a - \sqrt{r^2 - (y-b)^2}$$

and it is possible to assume values of y the working component of the current and calculate for the values of:

1st. Magn. Comp.

2nd. Primary Current.

3rd. Secondary Current.

4ty. Input in watts.

5th. (primary) (secondary) Copper losses.

6th. Output and Input.

7th. Efficiency.

8th. Primary power factor.

9th. R.P.M. Slip or o/o Slip.

10th. Syn. Speed (o/o of)

Methods of Calculation (Equations.

Assume y.

1st. Magnetizing Component.

Substitute in Equation $x = a - \sqrt{r^2 - (y-b)^2}$

2nd. Primary Current

$$I_1 = \sqrt{x^2 + y^2}$$

3rd. Secondary Current = $I_{21} = \sqrt{(y-b)^2 + (x-I_m \sin \theta)^2}$

4th. Input in Watts = Working component multiplied by the voltage = P L (Curve E)

5th. Primary and Secondary copper losses. (At standstill they make up total loss (QS) and are in ratio squares of secondary and primary currents if resistances secondary

and primary are the same. These losses vary with the load in a straight line ratio).

6th. Output = Input - losses = (P × F.)

7th. Efficiency = PF/PL.

8th. Primary Power Factor = PL/PM

9th. % Slip = FH/PH

10th. Syn. Speed (% of) = 100 - % Slip.

In the accompanying tables of the Appendix Figure 1 are given the values as calculated and in the section of Curves (Curve D) are shown the characteristic Curves of the motor as obtained in the test.

PART II

THE HEAT RUN

In this part of the study readings of temperature were taken at intervals of 5 minutes for 2 hours to constant temperature and a curve (curve sheet A) is plotted to show actual temperature on one scale and temperature rise on the other. This was not very complicated but is a very important factor in the behavior of any machine (motor) because excessive heating is disastrous, and limits the power that can be developed by the motor for short intervals and for continuous running. The latter being much lower than the former.

Another place where heating has a very prominent part in power of a motor is in the case of the motor that may be run either closed or open. The power at open running being from 20 to 50% more than at closed operation.

The method of manipulation of this test was simple.

Thermometer readings for temperature of primary coils were taken and recorded against time and these were plotted as above mentioned in Curve A.

PART III.

GENERAL RUNNING TEST OF MOTOR AT VARYING LOADS ON GENERATOR.

- -

Factors determined:

1st. Input.

2nd. Output.

3rd. Efficiency.

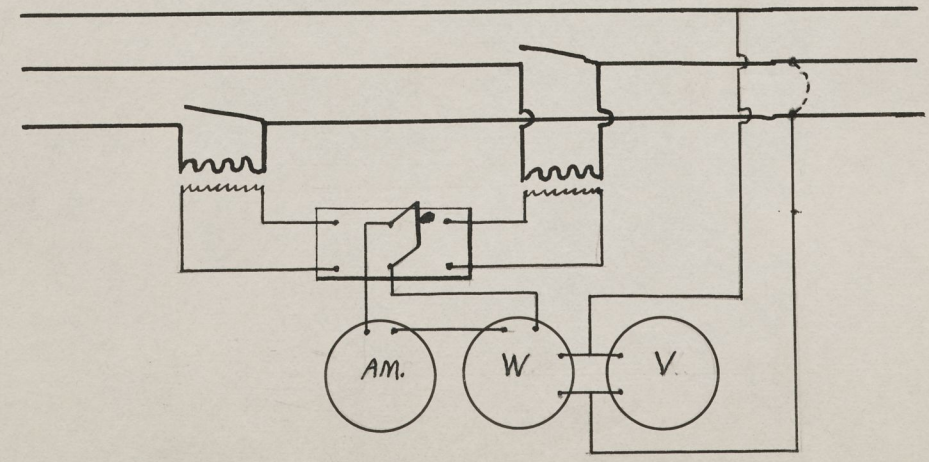
4th. Slip R. P. M.

5th. Power Factor.

6th. Regulation.

- - - - - - - - - - - - - - - - - -

1st. Input was 3 phase 220 volts and was measured by current transformers. Voltmeter, ammeter and wattmeter as in the following diagram:-



2nd. Direct current output was measured by ammeter and voltmeter.

Currents of (160 amps or less) flowed through a shunt and a millivoltmeter was used to measure the current.

3rd. Efficiency = Ratio output to input in %.

4th. Slip was counted by a revolving disc placed on shaft of motor with two diametrically opposed holes so placed that observer might look through them at a 60 cycle vibrator. And the number of times that the vibrator is observed to go up and down in a minute is the Slip in R.P.M.

5th. Power Factor was calculated by the Equation

$$\text{Cos } \theta = \frac{\text{Watts input}}{\sqrt{3}\ E\ I}$$

and checked by

$$\tan \theta = \sqrt{3}\ \frac{(W_1 - W_2)}{(W_1 + W_2)}$$

6th. Regulation = observed change in voltage divided by full load voltage and converted to Synchronous speed.

All data are recorded in tableNo. 2 or II of Appendix and in

Curve Sheet C of Curve Section.

CIRCLE DIAGRAM CALCULATIONS

E = 222.5 (Total Watts = 3 x E x Y.) 30 H.P.
T INDUCTION MOTOR

Work(g Comp. Cur. Y.	Magnetizing. Comp X X	Pri Cur I I	Sec. Cur. Emt I_2I	Input Watts Pl.
3.46	22.2	22.5	0.0	1420
10.00	32.0	33.5	11.9	3850
20.00	33.0	38.5	22.1	7700
30.00	34.0	45.3	29.0	11550
40.00	35.0	53.2	38.7	15400
50.00	37.0	62.2	48.8	19250
60.00	38.0	71.0	58.7	23100
70.00	46.0	84.0	70.8	27000

H.K. PRI Loss	F.H. SEC. Cu. Loss	Output Watts Motor - - - - -	Eff. %	PRI P. Fac	RPM SL-IP	% SL IP	% Syn Speed.
Wind, Fric. & Core Loss		0	0.0	.154	2.	.11	99.89
1625	1520	705	18.3	.298	9.	.55	99.89
1790	1670	4240	55.2	.520	28.	1.5	98.45
1955	1825	7770	67.3	.662	40.	2.22	97.78
2120	1980	11300	73.5	.750	66.	3.67	97.33
2450	2290	14510	75.5	.804	75.	4.17	95.83
2620	2440	19040	83.0	.845	98.	5.44	94.56
3940	3680	19380	83.0	.834	120	6.78	93.22

F I G U R E I

- - - - - - - - - -

DATA SHEET FOR CURVES

TEST OF M. G. SET RUNNING

Regulation-to-Syn. Speed = 1800 R.P.M.

A. C. INPUT				D. C. OUTPUT				% Reg. SL-Const.		
E	I	W	COS θ	E	I	Watts	Eff%	IP	Speed.	106.6
220	27.8	3480	.328	106	0.0	000.	0.0	9.	0.48	106.6
220	30.0	5400	.453	108	23.	2420	45.0	19.	2.20	109.0
220	30.6	6140	.527	109	30.	3150	51.3	21.	3.09	110.0
220	33.0	8200	.650	112	50.	5600	68.3	29.	6.50	114.0
220	36.2	10260	.741	119½	60.	7180	70.0	40.	12.60	122.0
220	42.8	13400	.822	124	78.	9680	72.2	54.	17.00	128.0
220	50.0	17300	.900	124	100.	12400	72.7	65.	17.10	128.5
220	52.0	17700	.910	117	110.	13000	73.0	74.	12.6	122.0
220	64.0	21900	.880	120	138.	16550	73.4	102	16.5	127.0
220	66.0	22900	.920	117	146.	16600	73.5	104.	15.2	125.0
220	66.0	24100	.925	111	149.	17100	74.5	106.	10.2	118.0
220	70.8	25000	.930	112	160.	18000	74.5	108.	10.6	119.0

FIGURE 2

EFFICIENCY OF M. G. SET.

A.C. IN-PUT A	A.C. IN-PUT B	A.C. TOTAL IN-PUT. Total x 20 =Watts	D.C. OUT - PUT E	D.C. OUT - PUT I	D.C. OUT - PUT Watts	EFF.
220	-90	2,600.	93.5	0.0	000.	00.0
240	-65.	3,500.	109.0	9.0	981.	28.0
265	-45.	4,400.	110.0	17.0	1,870.	42.5
300	00.	6,000.	114.0	31.5	3,590.	59.0
335	30.	7,300.	115.5	38.0	4,380.	60.0
375	7215	8,950.	120.0	49.0	5,880.	65.8
387	92.5	9,590.	120.0	54.0	6,480.	67.5
400	105.0	10100.	120.0	57.0	6,830.	67.7
465	165.0	12600.	121.0	68.0	8,220.	65.0
450	150.0	12000.	122.0	71.0	8,660.	72.0
490	190.0	13600.	122.0	81.0	9,880.	72.7
555	250.0	16100	122.0	94.0	11,500.	71.5
590	290.0	17600.	121.0	107.5	13,000.	73.4
645	333.0	19560.	121.0	119.5	14,500.	74.1
680	368.0	20960.	120.5	131.0	15,800.	75.5
750	435.0	23700.	120.0	148.0	17,750.	75.0
745	427.5	23440.	120.0	148.0	17,750.	75.7
770	448.5	24380.	120.0	156.0	18,700.	76.7
787	480.0	25340.	118.0	161.5	19,000.	75.0
825	487.0	26240.	116.0	169.5	19,700.	75.0

FIGURE 3

HEAT RUN INDUCTION MOTOR IN M.G. SET.

---oOo---

Out-put Generator 160 amps at slightly varying voltage due to varying frequency at power house.

Temp. Room 322° Centigrade

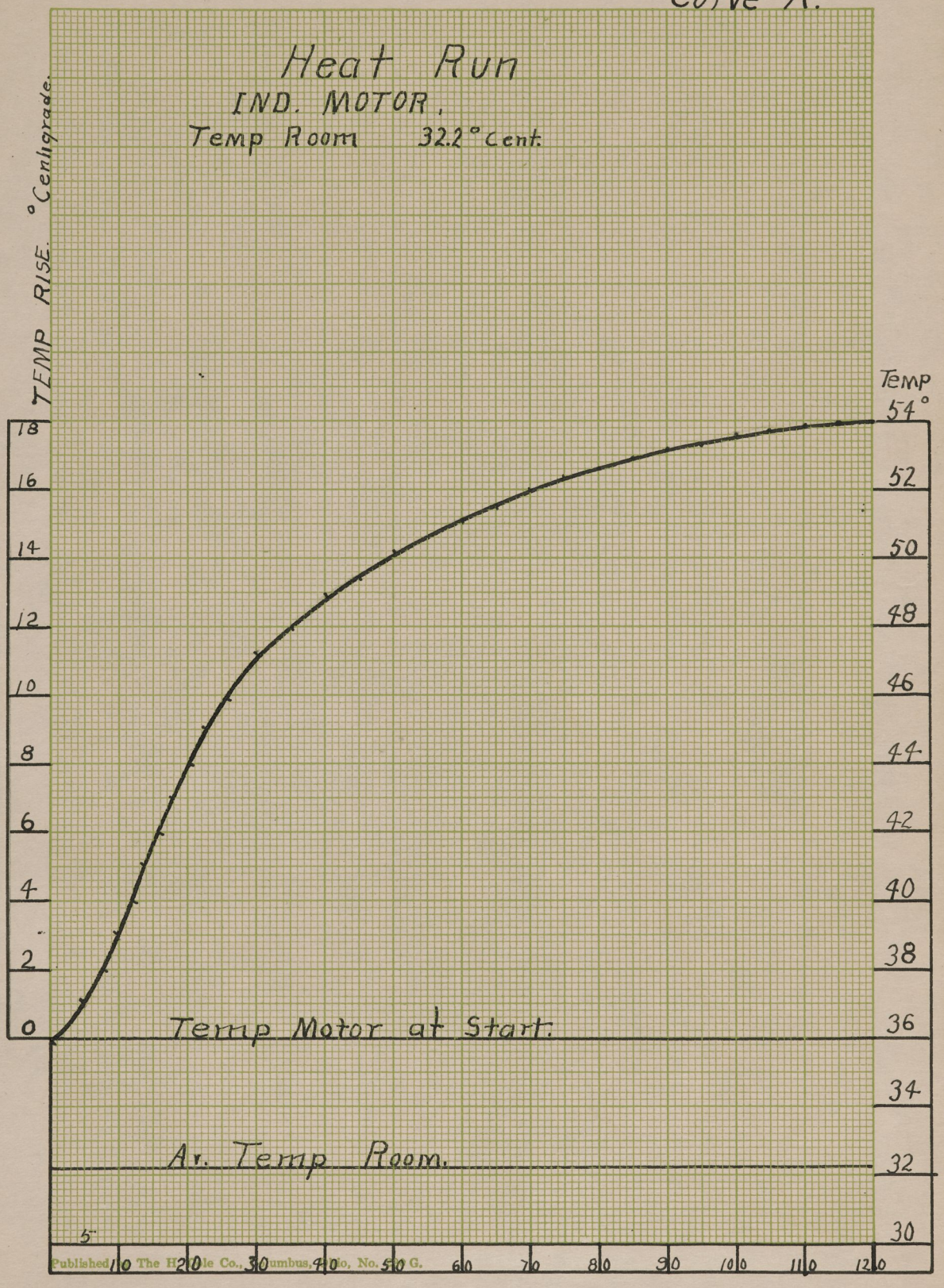
~~IDLE~~ TIME	LAPSE (Minutes)	TEMP. CENTIGRADE	(Rise)
3:25	0	35.5	00.0
3:30	5	36.8	1.3
3:35	10	38.5	3.0
3:40	15	41.5	6.0
3:45	20	44.4	8.9
3:50	25	46.0	10.5
3:55	30	47.3	11.8
3:60	35	48.2	12.7
3:65 or 4:05	40	48.9	13.4
4:10	45	50.0	14.5
4:15	50	50.2	14.7
4:20	55	50.8	15.3
4:25	60	51.2	15.7
4:30	65	51.4	15.9
4:35	70	52.0	16.5
4:40	75	52.5	17.0
4:45	80	52.4	16.9
4:50	85	52.8	17.3
4:55	90	53.1	17.6

---(SEE NEXT PAGE)---

5:00	95	53.1	17.6
5:10	105	54.0	18.5
5:20	115	53.9	18.4
5:30	125	54.2	18.7

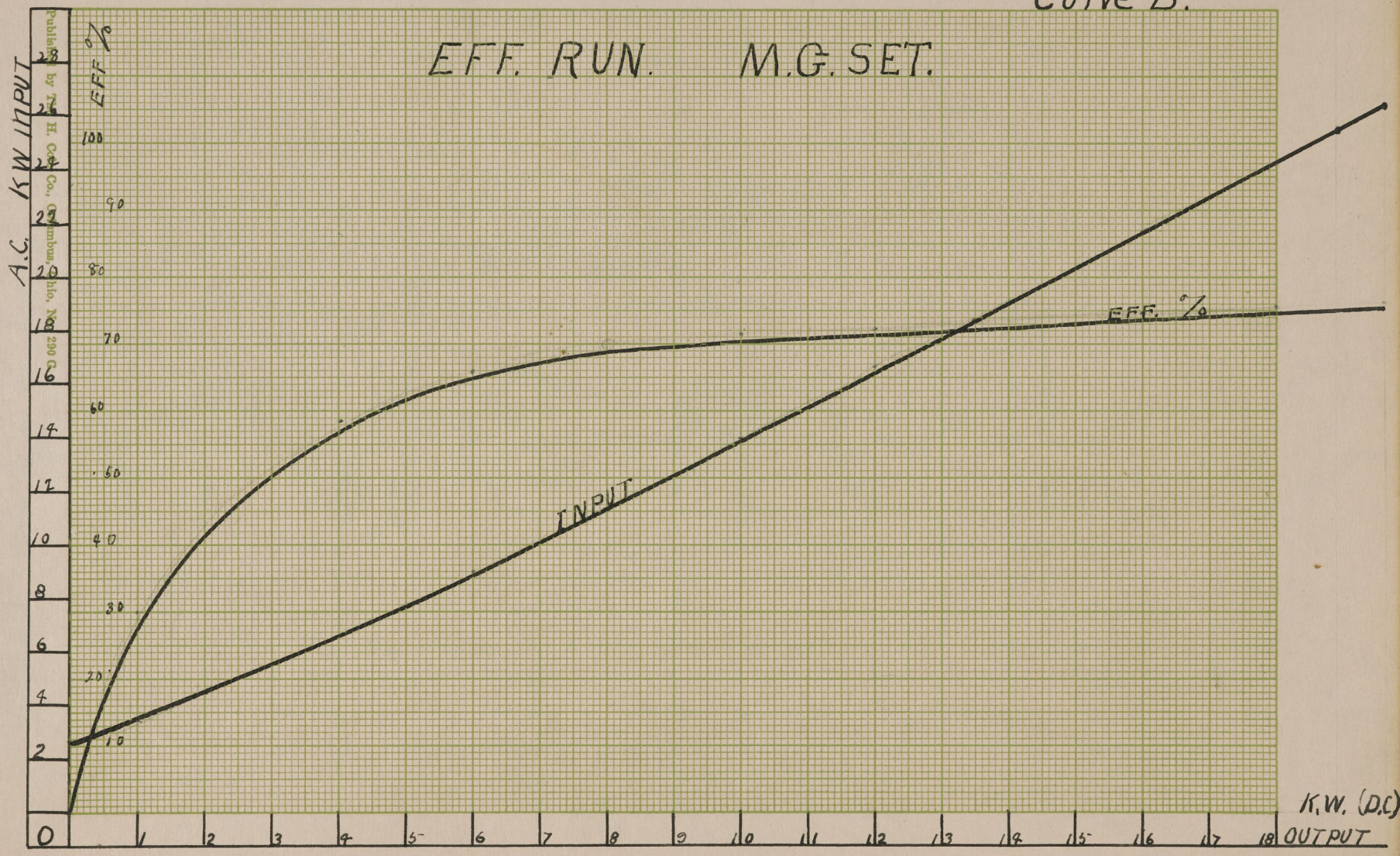
F I G U R E 4

Curve A.

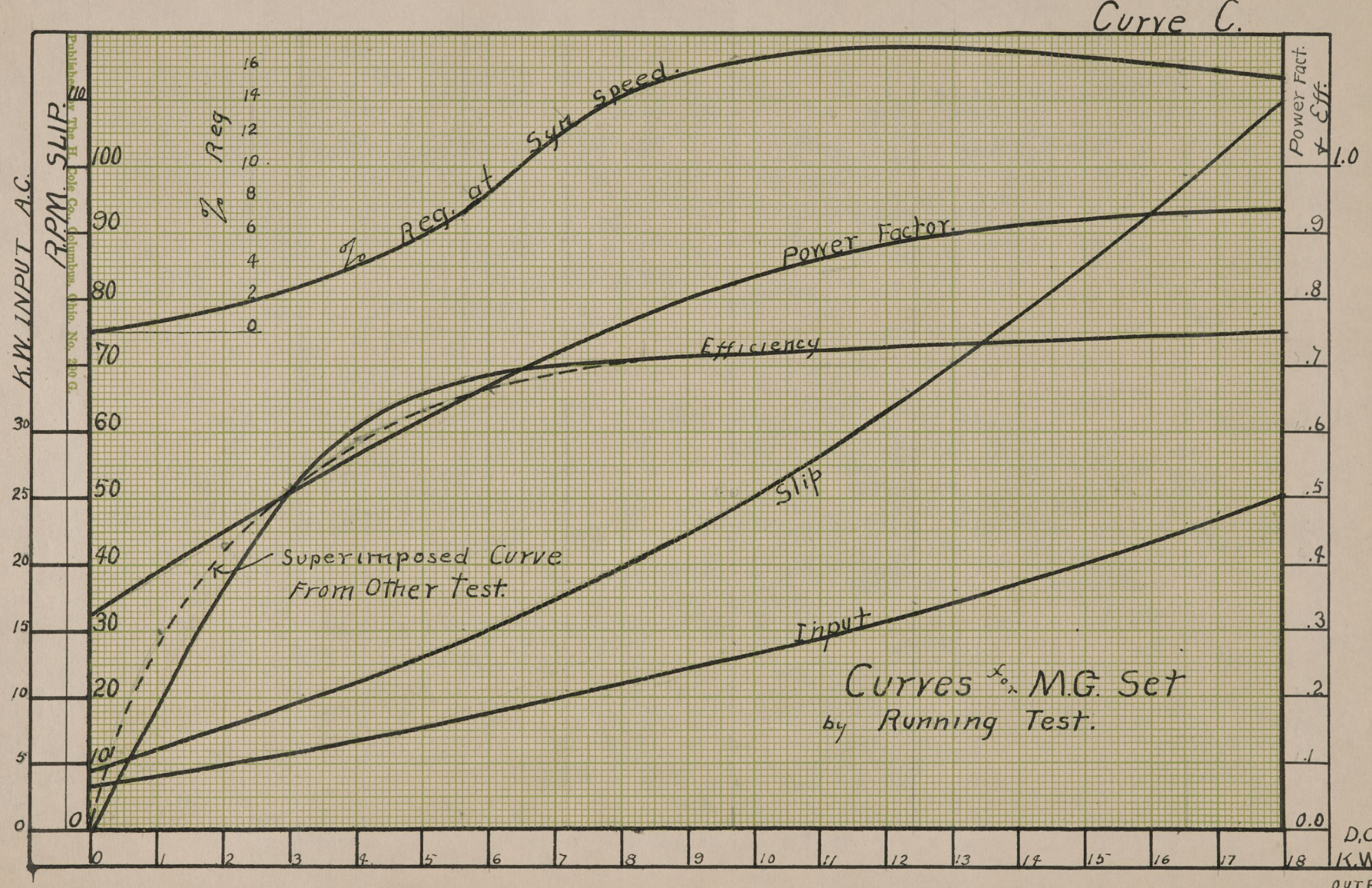


Published by The H. Wolle Co., Columbus, Ohio, No. 5 10 G.

Curve B.


EFF. RUN. M.G. SET.
A.C. K.W. INPUT
EFF. %
100
90
80
70
60
50
40
30
20
10
EFF. %
INPUT
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
K.W. (D.C.) OUTPUT
Published by The H. Co. Co., Columbus, Ohio, No. 290 C6

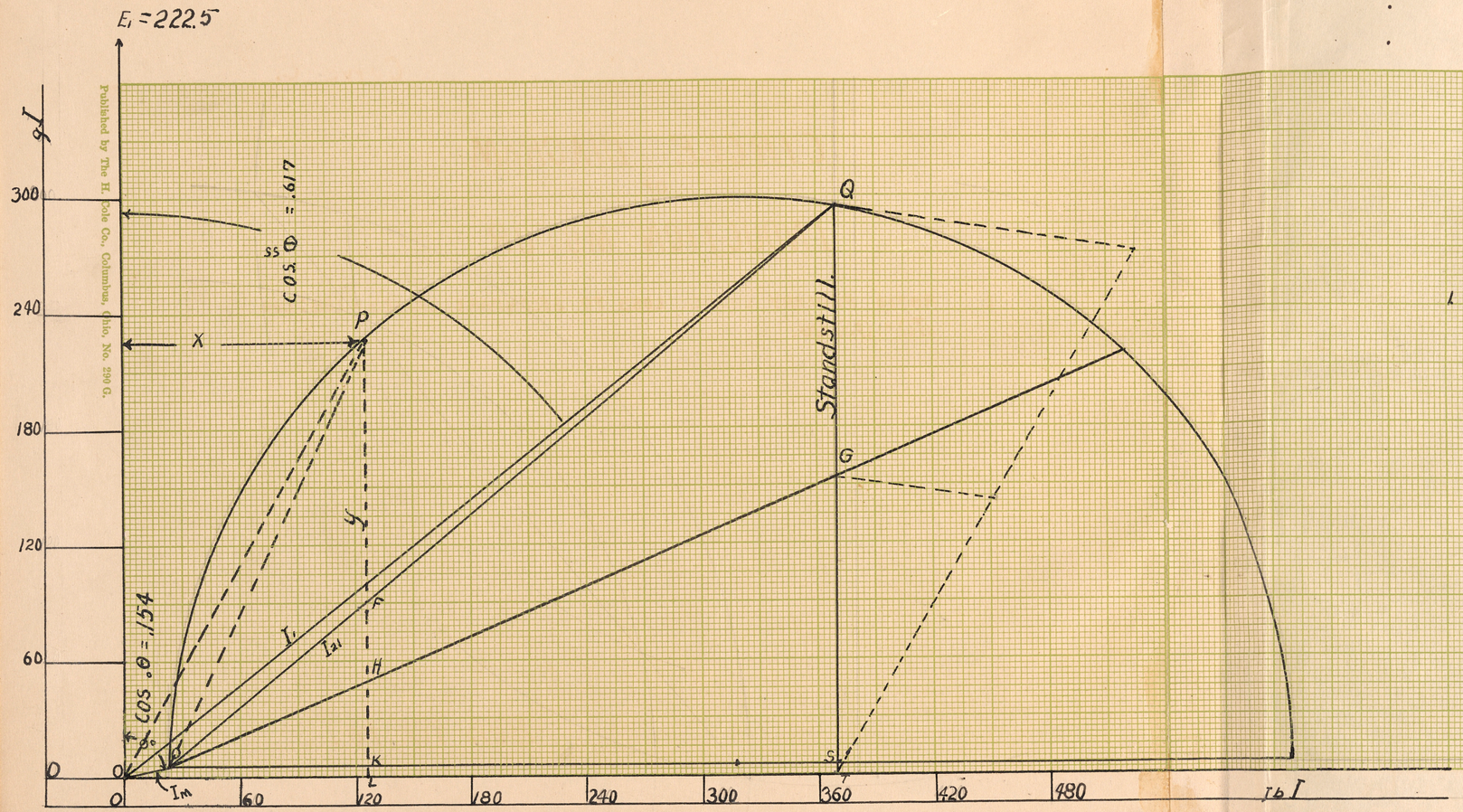
61


Curve C.
K.W. INPUT A.C.
R.P.M. SLIP.
% Reg.
% Reg. at Syn Speed.
Power Factor.
Efficiency
Slip
Input
Superimposed Curve From Other Test.
Curves of M.G. Set by Running Test.
Power Fact. & Eff.
D.C. K.W. Output
Published by The H. Cole Co. Columbus, Ohio. No. 810 G.

Curve E.

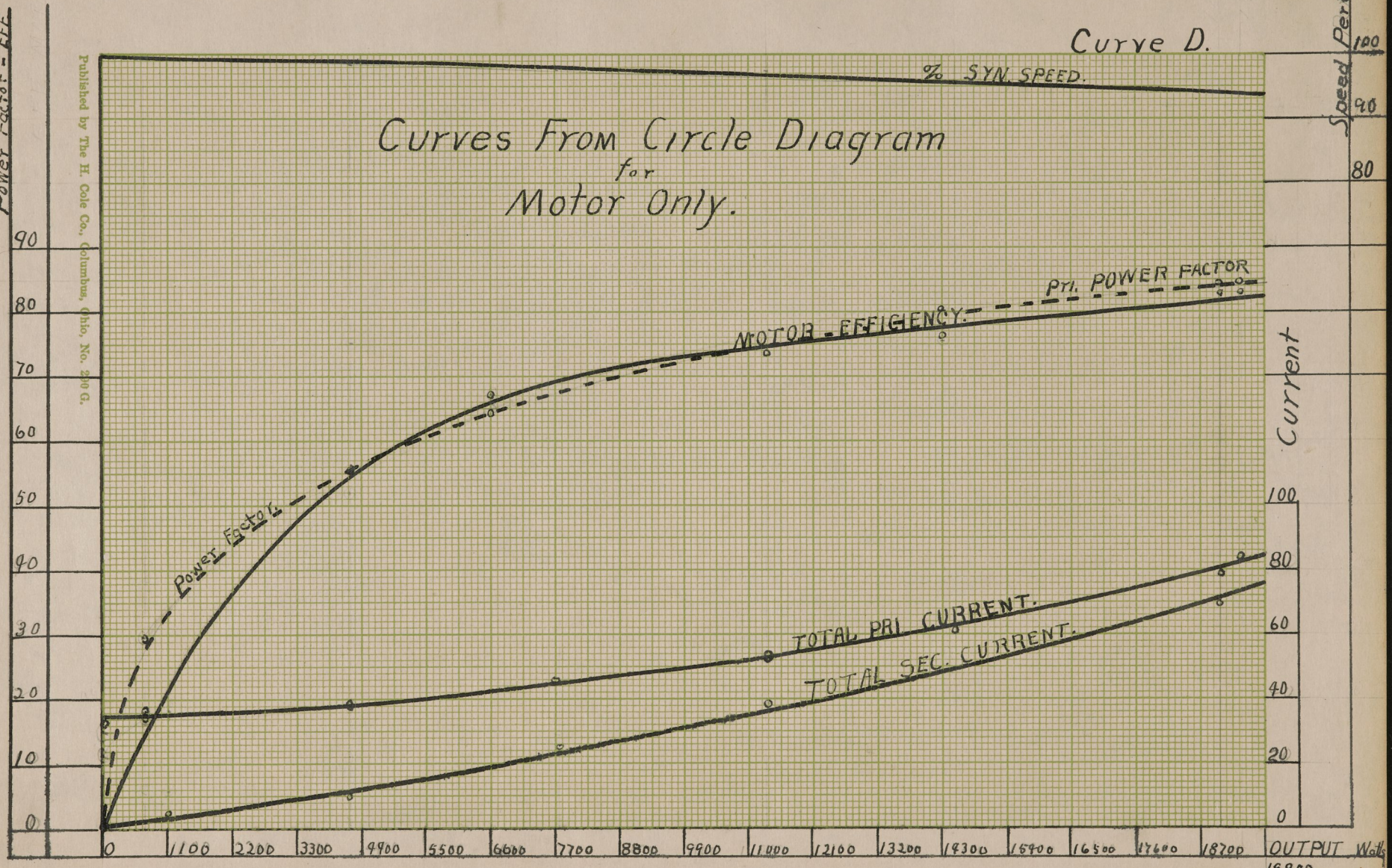
CIRCLE DIAGRAM
of
INDUCTION MOTOR

1 RATIO PRIMARY COPPER LOSS TO SECONDARY LOSSES = 1.08 : 1.00
= TO - GS/QG.



Published by The H. Dole Co., Columbus, Ohio, No. 290 G.

Ben White.


Curve D.
% SYN. SPEED.
Curves From Circle Diagram
for
Motor Only.
Pri. POWER FACTOR
MOTOR - EFFICIENCY.
Power Factor
TOTAL PRI CURRENT.
TOTAL SEC. CURRENT.
Power Factor - Eff.
Speed Per Cent Syn.
Current
OUTPUT Watts
0
1100
2200
3300
4400
5500
6600
7700
8800
9900
11000
12100
13200
14300
15400
16500
17600
18700
19800
Published by The H. Cole Co., Columbus, Ohio, No. 200 G.