

TEST OF SINGLE PHASE
INDUCTION MOTOR

-By-

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The motor was tested to determine its characteristics.

These include:

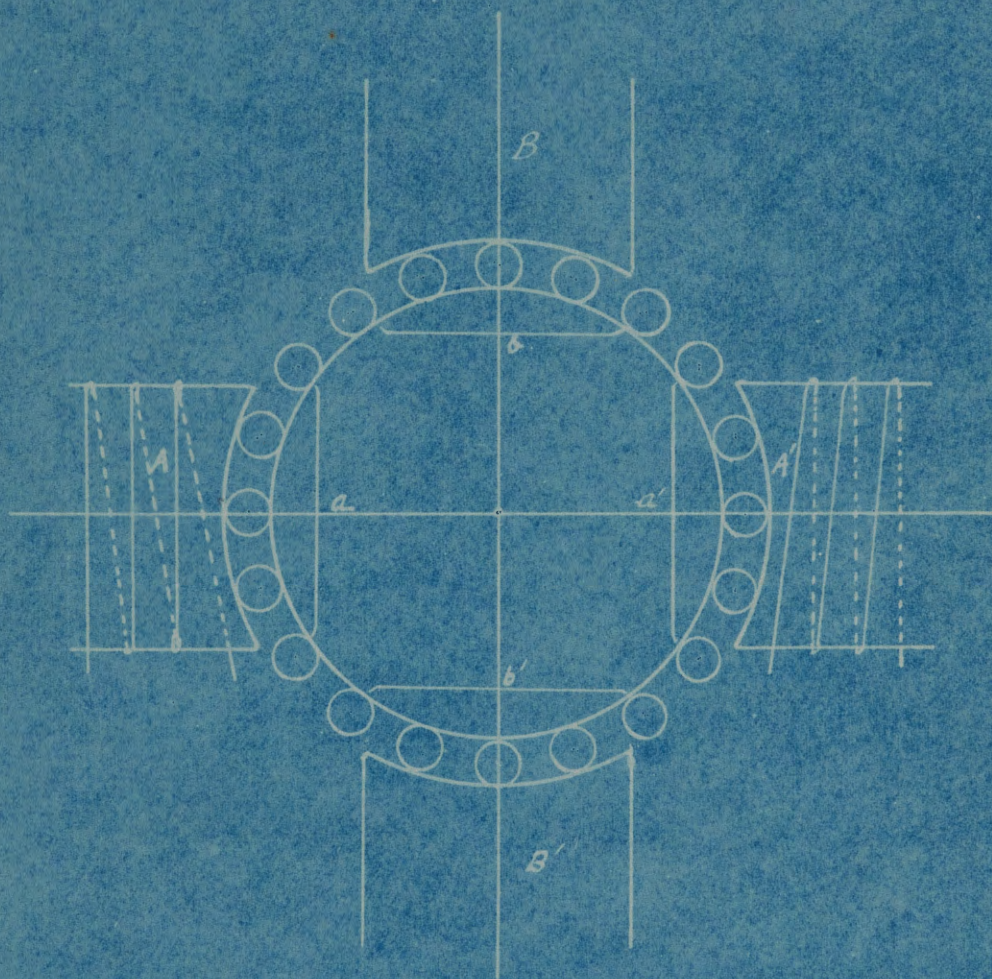
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DEVELOPMENT OF REVOLVING FIELD.

It is well known that the single phase induction motor does not have a starting torque. After the motor has been brought up to speed it provides itself a rotating magnetic field by the reactions of the rotor currents upon the stator flux. That such is the case may be shown non-mathematically. Assume a two-pole motor (plate I) the stator winding of which is supplied with a single-phase alternating current, producing an oscillating field between the poles A A'. The rotor currents produce a field at right angles to the main field, and for convenience assume this to be represented by the poles B B'. In commercial machines no such empty hole spaces exist, as practically all of the stator is covered with coils.

The inductors of the revolving rotor have emf's induced in them due to two actions, namely motion through the field and the time rate of change of the flux treading the coils. The first we shall designate as a rotational emf. and the second as a transformer emf.

The inductors a a' will always have a rotational emf. set up in them except when the stator field passes through zero value. The amplitude of this emf. for any given speed will be proportional to the instantaneous value of the stator flux. Conductors a a' may be considered equivalent to closed coils, and the current flowing in them will produce a field in direction B B'. Neglecting temporarily the I R drop in the rotor, the emf. induced in a a' may be placed equal to $\frac{d\phi}{dt}$, where ϕ_r denotes the cross field developed by the currents due to the motion of the rotor in the main field. The rotational emf. is in time phase with the main field, hence the cross field ϕ_r will be in time quadrature with it. The direction of the main field and the motion of the rotor inductor are such that the emf. generated in a a'



MAIN AND QUADRATURE FIELDS, SINGLE-PHASE
INDUCTION MOTOR

PLATE I

is positive. The rotor currents are in such direction that when pole A is of north polarity and decreasing, pole B will be of like sign but increasing, reaching its maximum strength one-quarter of a period later. The strength of pole B decreases after a similar lapse of time, the main field reverses and a north pole begins to build up at A'. That is, the main field and quadrature field so combine that a north pole travels around the stator in the direction A B A' B at synchronous speed. Hence there exists a rotating field produced by the combined action of stator and rotor currents. This simple explanation gives an idea of the production of the rotating field in the simple-phase induction motor, but it does not consider all the reactions which occur.

The inductors b b' moving in the quadrature field have a rotational emf. induced in them, in the same manner as those passing through the main field, and this is of maximum positive value when the north pole at B attains its highest value. In addition to these two rotational emfs. the varying fields A A' and B B' set up transformer emf's. in coil groups b b' and a a' respectively. Consequently, there are four emfs, to be considered before the actual rotor currents which produce the quadrature field can be determined.

The rotational emf. induced in inductors a a' is of maximum positive value when the pole A is at its greatest north polarity, but the transformer emf. set up in these bars by the quadrature field is at the same moment of maximum negative value. Hence the actual emf. (E_a) existing in A A' is the algebraic sum of these two voltages. The rotational emf. due to the main field must be greater than the transformer emf. of the quadrature field; in fact

the latter is of such strength that the actual emf. (E_a) will be just enough to establish the current which produces the field $B B'$. Since this quadrature field is at right angles to the main field, its m.m.f. cannot be furnished directly by the stator magnetizing current, so we must investigate further to see how it is taken, as it must be, from the line. It must be remembered that the impedance of the rotor coils is here assumed to be such that the $I Z$ drop is negligible; if this is not the case, the rotational and transformer emf's will not be in time opposition and their vector sum, instead of algebraic sum, must be considered.

The main field, by transformer action, induces an emf. in bars $b b'$, and this is opposed to the emf. developed in the same inductors by their motion through the quadrature field. The resultant emf. (E_b) in these conductors sets up a current affecting the main field and consequently the current drawn from the line. The current flowing in conductors $b b'$ due to E_b is equal to that existing in bars $a a'$, which latter is that producing the cross m.m.f. moreover, the current $b b'$ is in such direction that it increases the magnetizing current taken from the line, the increment being that which would be necessary to directly magnetize the quadrature field. The reluctance of the cross field's magnetic circuit is substantially the same as that of the main field, consequently the m.m.f. required for both will be the same, and obviously therefore, a two-phase motor run on one phase will draw twice its normal magnetizing current. This conclusion is borne out by actual practice, tests showing that the magnetizing current of a single-phase motor is double that taken per phase by a two-phase and three times that required by a three-phase machine, the potential difference, frequency and turns per phase winding being the same.

At synchronous speeds the two component fields are of equal strength; accordingly they combine to give a circularly rotating field. Below synchronous speed the rotating emf. in the bars $a a'$ is reduced in inverse proportion to the slip, and thus the quadrature field diminishes, while the main field remains constant.

The maximum torque which a motor is capable of exerting, other things being equal, depends upon the average value of the magnetic field in which the rotor moves. This mean value, neglecting I R drop and leakage, is in polyphase induction motor independent of the slip, while for the corresponding single-phase machine the average value of the field decreases as the slip increases; thus the pull-out torque of a polyphase machine connected single phase will be less than when normally operated.

The single-phase induction motor tested was started up as a repulsion motor. When the speed reached 1500 revolutions per minute, a mechanism moving by centrifugal force, lifted the brushes from the commutator and automatically short-circuited the commutator thus making the motor a squirrel cage induction motor. When the switch was opened and the motor was stopping, at the speed of 950 R.P.M., the mechanism went back to its stand still position thus pulling the brushes back on the commutator and removed the short-circuit connection.

THE REPULSION MOTOR.

The main field or stator is connected to the supply lines while the wound armature is short circuited through brushes placed 180 electrical degrees apart. The repulsion motor is fundamentally a transformer, with the primary winding and core stationary.

The secondary is like an ordinary direct-current armature, in which the armature conductors and core rotate, while the short-circuited brushes are stationary. Hence, while the conductors in the secondary winding rotate, the secondary circuit remains in a definite position with respect to the stator. In the repulsion motor as in the single-phase induction motor, there are transformer and speed fields, whose reactions with the armature currents produce the desired torque.

At standstill the speed field is zero and the starting torque is produced by the reactions between the induced armature current and the stator field. The magnitude of the starting torque depends upon the relative position of the armature brushes and the direction of the stator field. If the brushes are in line or at right angles to the direction of the stator field flux, no torque is produced.

-HEAT RUN-

The motor is guaranteed by the manufacturer that the temperature rise will not exceed forty degrees Centigrade, under continuous operation and full load. A test was run for two hours and forty minutes with eighty per cent full load.

A thermometer was so placed that the temperature of the field windings could be measured. The load on the induction motor was absorbed by a direct-current motor run as a generator. This generated power was absorbed by a rheostat.

The data for this test are on sheet number 10; curve on plate II.

STARTING CURRENT AND TORQUE.

To determine the starting current and the starting torque, the rotor was locked, and at reduced voltage readings of ammeter, voltmeter and wattmeter were recorded. Since the power factor remains constant, these readings were raised to what they would be at 110 volts. The current varies directly as the voltage applied, and the watts vary as the ratio of the currents squared.

The torque was measured by locking the rotor with a prony-brake and measuring the pull with a spring balance.

NOTE: When the rotor is locked, the motor is a repulsion motor because the commutator bars are on upon circuit and the brushes are resting on the commutator.

Data are on sheet number 12; curve on plate III.

To determine the different speeds at which the motor changed from the repulsion to the induction motor, and back again, a tachometer was used to measure the revolutions per minute. The motor was run at no load and a reading was taken when the repulsion motor changed to inductions. When the switch was opened another reading was taken when the induction motor changed back into repulsion. When the motor changed from one to the other type, the force of the short-circuiting mechanism made a noise loud enough to hear, and at this point the readings were taken. As the motor speeded up, when the switch was closed, the repulsion motor changed to the induction type at 1500 r.p.m. When the switch was opened, the change occurred at 950 r.p.m.

CIRCLE DIAGRAM.

(Can be used to obtain efficiency and general characteristics of motor).

An induction motor with a variable load is equivalent to a circuit having constant reactance and variable resistance; hence for variable load the locus of the secondary current is a circle.

For a polyphase induction motor only two sets of readings are required, namely, at no load (corresponding to open secondary on a transformer) and with rotor locked (corresponding to short circuit conditions for a transformer). When the rotor, of the motor tested was locked, the conditions were those of a repulsion motor and so readings taken here would not be on a corresponding circle diagram for an induction motor.

Readings of amperes, volts, and watts were taken at no load. The ammeter gives the magnetizing current, and the wattmeter the core losses windage, and friction. The magnetizing current has components in time phase and time quadrature with the voltage and their magnitudes are determined by the amperes, volts, and watts taken at no load. To obtain other points on the circle, readings were taken at different loads. The currents corresponding to these loads were platted on the diagram and through the terminals of these current vectors, a circle was drawn, which is the circle diagram.

The resistance of the field circuit was determined by connecting an ammeter and voltmeter on the line, using direct-current, and taking consecutive readings of amperes and volts, the amount of current flowing being changed by a variable rheostat. The data for this test is on sheet

On the circle diagram, (Plate V).

FA is primary current.

OA "" secondary current.

FO "" magnetizing current.

AE "" input in watts.

DE "" core loss, windage, friction, and no load
copper loss.

CD "" primary copper loss.

BC "" secondary copper loss.

In order to draw the line OC, the point C is found by laying off a distance corresponding to the number of watts equal to the I^2R loss corresponding to current at A. (Point A is locus point of current at 125 per cent load).

Since the voltage generated depends upon the rate of cutting lines of force, the secondary voltage is proportional to the rotor slip. Likewise the reactance in the rotor circuit is directly proportional to the frequency of the secondary current, and hence, also to the slip.

For this reason.

$$\text{Slip} = \frac{\text{rotor loss}}{\text{rotor input}} = \frac{BC}{AC}$$

Hence, the point B can be found. Through this point draw the line OB, and it will intercept the circle at the point corresponding to the current at locked load.

The data for the circle diagram are on sheet

To obtain data from the circle diagram for the performance curves use the following formulae:

$$\text{Power factor} = \frac{AE}{AF}$$

$$\text{Efficiency} = \frac{AB}{AE}.$$

DATA--HEAT RUN.

TIME	TEMP. °C	TEMP. RISE	TIME	TEMP. °C	TEMP. RISE
2:30	22.2		4:50	53.3	0.0
2:35	24.7	2.5	4:55	53.3	0.0
2:40	27.2	2.5	5:00	53.3	0.0
2:45	29.6	2.4	5:05	53.3	0.0
2:50	31.8	2.2			
2:55	33.8	2.0			
3:00	35.8	2.0			
3:05	37.6	1.8			
3:10	38.9	1.3			
3:15	40.4	1.5			
3:20	41.6	1.2			
3:25	42.8	1.2			
3:30	43.9	1.1			
3:35	44.9	1.0			
3:40	45.6	0.7			
3:45	46.6	1.0			
3:50	47.5	0.9			
3:55	48.3	0.8			
4:00	49.0	0.7			
4:05	49.8	0.8			
4:10	50.6	0.8			
4:15	51.3	0.7			
4:20	52.0	0.7			
4:25	52.4	0.4			
4:30	52.6	0.2			
4:35	52.8	0.2			
4:40	53.1	0.3			
4:45	53.3	0.2			

80% FULL LOAD

NET RISE 31.1 °C

TIME 2 hrs. 40 min.

E = 106

I = 42

W = 3400

ESTIMATE OF FINAL TEMPERATURE, FROM PRECEDING TEST.

NO LOAD READINGS

$$E = 110$$

$$I = 19.78$$

$$W = 540$$

$$I^2 R \text{ LOSS} = 26.6 \text{ WATTS}$$

$$\text{IRON LOSS} = 513 \text{ WATTS}$$

Iron loss is approximately proportional to 1.6 th. power of impressed voltage.

WITH $I = 42$

$$E = 106$$

$$W = 3400$$

$$I_1^2 R_1 \text{ LOSS} = 120 \text{ WATTS}$$

$$I_2^2 R_2 \text{ LOSS} = 111 \text{ WATTS}$$

$$\text{IRON LOSS} = \underline{484 \text{ WATTS}}$$

$$\text{TOTAL LOSS} = 715 \text{ WATTS}$$

WITH $I = 52$

$$E = 110$$

$$I_1^2 R_1 \text{ LOSS} = 184 \text{ WATTS}$$

$$I_2^2 R_2 \text{ LOSS} = 197 \text{ WATTS}$$

$$\text{IRON LOSS} = \underline{513 \text{ WATTS}}$$

$$\text{TOTAL LOSS} = 894 \text{ WATTS}$$

Temperature rise is proportional to power loss.

So at end of the heat test with full load, and

$$I = 52 \text{ AMP.}$$

$$E = 110 \text{ VOLTS,}$$

temperature rise should be $894 \times 31.1 = 38.9 \text{ }^\circ\text{C.}$

DATA E. M. F. -- TORQUE.

(Corrected Readings)

E	TORQUE '#
120	63
110	59
89.8	49
72.5	41
62.8	31
58.5	25
55.5	23
51.8	16
46.2	12
43.0	11
34.0	7
16.0	3

STARTING I. = 136 AMPERES.

DATA--MEASUREMENT OF FIELD RESISTANCE.

-(Corrected Readings)-

:VOLTS:	:AMPERES:	:RESISTANCE: (Ohms)
0.056	0.822	0.0681
0.0628	0.918	0.0684
0.0775	1.132	0.0684
0.091	1.336	0.0681
0.1042	1.500	0.0695
0.1192	1.743	0.0684
0.126	1.842	0.0683
0.1322	1.925	0.0688
0.156	2.297	0.0678
0.204	2.97	0.0681
0.247	3.594	0.0686

MEAN RESISTANCE 0.0684 OHMS

TEMPERATURE 25 °C

INSTRUMENTS USED:

Weston Millivoltmeter No. 13962

Weston Millivoltmeter No. 7864 (with shunt).

Resistance of field at 25 °C = 0.0684 ohms.

Resistance of field at 0°C = 0.0619 ohms.

Resistance of field at 44° C = 0.07334ohms.

(Using a temperature coefficient = 0.0042 at 0°).

PERFORMANCE TEST.

1	2	3	4	5	6	7	8
PRIMARY Emf.	PRIMARY I.	PRIMARY Watts.	PRIM.P.F.— θ — Cos. θ		SIN θ .	PRIMARY NO LOAD Copper loss. Iron & friction loss.	
			$\frac{(3)}{(1) \times (2)}$			$0.068 \times (2)^2$	$(3) - (7)$
110	19.45	540	0.252	75°36'	0.9677	27	513
110	21.15	767	0.3295	70°45'	0.9441	30.5	513
110	21.9	912	0.378	67°47'	0.9258	32.6	513
110	22.25	1195	0.488	60°48'	0.8729	33.7	513
110	24.35	1463	0.546	56°54'	0.8377	40.4	513
110	29.6	2308	0.708	44°45'	0.7040	59.6	513
110	31.8	2657	0.759	40°38'	0.651	68.8	513
110	35.15	3025	0.783	38°27'	0.6218	84.4	513
110	40.2	3625	0.82	34°54'	0.5721	110.0	513
110	53.5	5020	0.853	31°27'	0.5217	194.7	513

9	10	11	12	13	14	15
TOTAL PRI. LOSS WITH FRICTION.	SEC. INP. SYN. WATTS	ROTOR EX- TERNAL TOR- QUE IN #'	EX- TOR- COMPON- ENT I_1 .	POWER QUAD. COMP. PRI. AMP.	POWER QUAD. COMP. SEC. AMP.	QUAD. COMP. SEC. AMP.
(8)-(7)	(3)-(9)	(10)- <u>255.6</u>	$I \cos \theta$	$I \sin \theta$	$I_2 \cos \theta_2$	$I_2 \sin \theta_2$
			(2) x (4)	(2) x (6)	(12)-4.9	(13)-B.8
540	0	0	4.9	18.83	0	0
543.5	223.5	0.875	6.96	19.95	2.06	1.15
545.6	366.4	1.43	8.28	20.3	3.38	1.5
546.7	648.3	2.53	10.85	19.4	5.95	0.6
553.4	909.6	3.54	13.30	20.4	8.40	1.6
572.6	1735.4	6.77	20.95	20.83	16.05	2.03
581.8	2075.2	8.1	24.15	20.7	19.25	1.9
597.4	2427.6	9.46	27.55	21.85	22.65	3.05
623.0	3002.0	11.75	32.9	23.0	28.0	4.2
707.7	4312.3	16.8	45.6	27.9	40.7	9.1

16	17	18	19	20	21	22
TOTAL SEC.I	SEC.COEF.	ROTOR SLIP	MOTOR	MOTOR	MOTOR	ROTOR
$\sqrt{(14)^2 - (15)^2}$	LOSS $I_2^2 R_2$	S (17)	OUTPUT	OUTPUT	EFF. %	SPEED
		(10)	WATTS	HP--(19)	$\frac{746}{(3)} \frac{(19)}{(3)} \times 100$	% SYN.
			(10)-(17)			$100 \times (1 - (18))$
0.0	0.0	0.0	0.0	0.0	0.0	100
2.35	0.76	0.0034	222.74	0.35	29.63	99.66
3.7	1.83	0.0052	364.57	0.488	40.1	99.48
5.98	4.9	0.0076	643.6	0.862	53.8	99.24
8.55	10.03	0.0114	899.3	1.195	61.45	98.86
16.2	36.0	0.0207	1699.4	2.275	73.6	97.93
19.32	51.3	0.0247	2023.9	2.72	76.4	97.53
22.85	71.5	0.0295	2356.1	3.16	77.1	97.05
28.35	110.0	0.0366	2892.0	3.88	79.8	96.34
41.6	237.5	0.055	4074.8	5.47	81.4	94.5

SEC. RES. = 0.137 OHMS.

PRI. RES. = 0.068 OHMS.

DATA -- CALIBRATION OF INSTRUMENTS.

VOLTMETER NO. 6202			AMMETER NO. 17396		
STANDARD	VOLTMETER	CORRECTION	STANDARD	AMMETER	CORRECTION
47.1	46.6	+0.5	1.23	1.235	-0.005
58.4	47.9	+0.5	1.325	1.332	-0.007
67.25	66.7	-0.45	1.46	1.47	-0.01
71.6	71.45	+0.15	1.58	1.585	-0.005
89.1	89.3	-0.2	1.777	1.7825	-0.0055
95.15	95.25	-0.1	1.885	1.88	+0.005
100.2	100.35	-0.15	2.16	2.15	+0.01
103.1	103.45	-0.25	2.425	2.395	+0.03
114.4	114.7	-0.3	2.82	2.80	+0.02
110.5	110.9	-0.4	3.52	3.52	0.0
			3.64	3.64	0.0
			1.14	1.14	0.0
			1.18	1.18	0.0

Air Temperature 27.5°C.

WESTON Ammeter 17396	WESTON Voltmeter 6202	E I	THOMSON Wattmeter 81954	CORRECTION.
1.817	113.25	205.775	203	+2.775
1.392	114.2	158.966	156	+2.966
2.254	112.3	253.124	251	+2.124
2.724	112.8	307.267	304	+3.267
3.517	111.8	393.200	389	+4.200
1.000	113.5	113.5	104	-0.500

GENERAL ELECTRIC
Wattmeter
198719

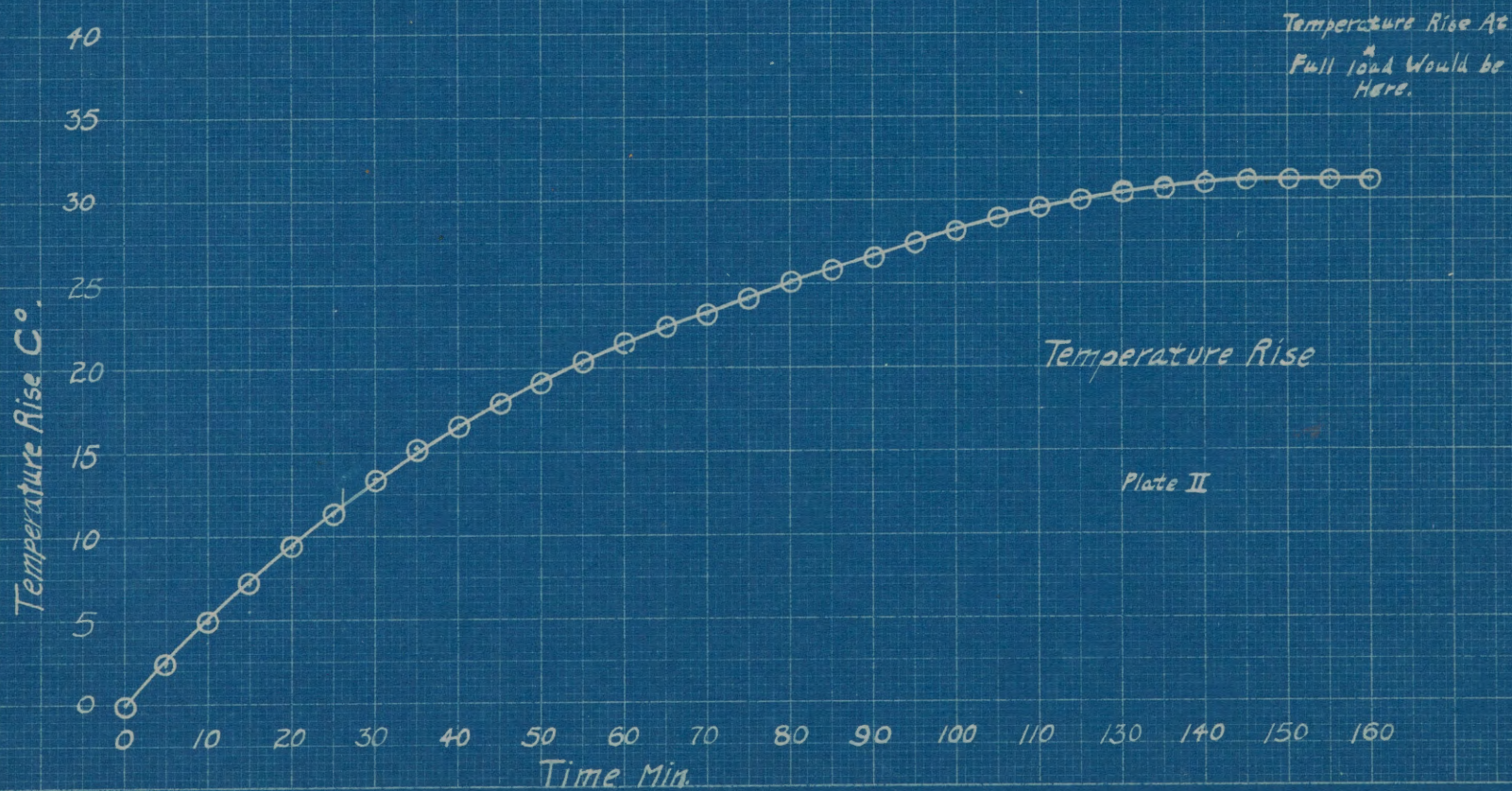
0.980	110.6	108.388	101	+7.388
1.353	110.6	149.642	148	+1.642
1.7745	110.6	196.259	196	+0.259
2.316	114.2	264.487	261	+3.487
3.52	113.15	398.288	392	+6.288
4.42	113.65	502.333	453	+49.333

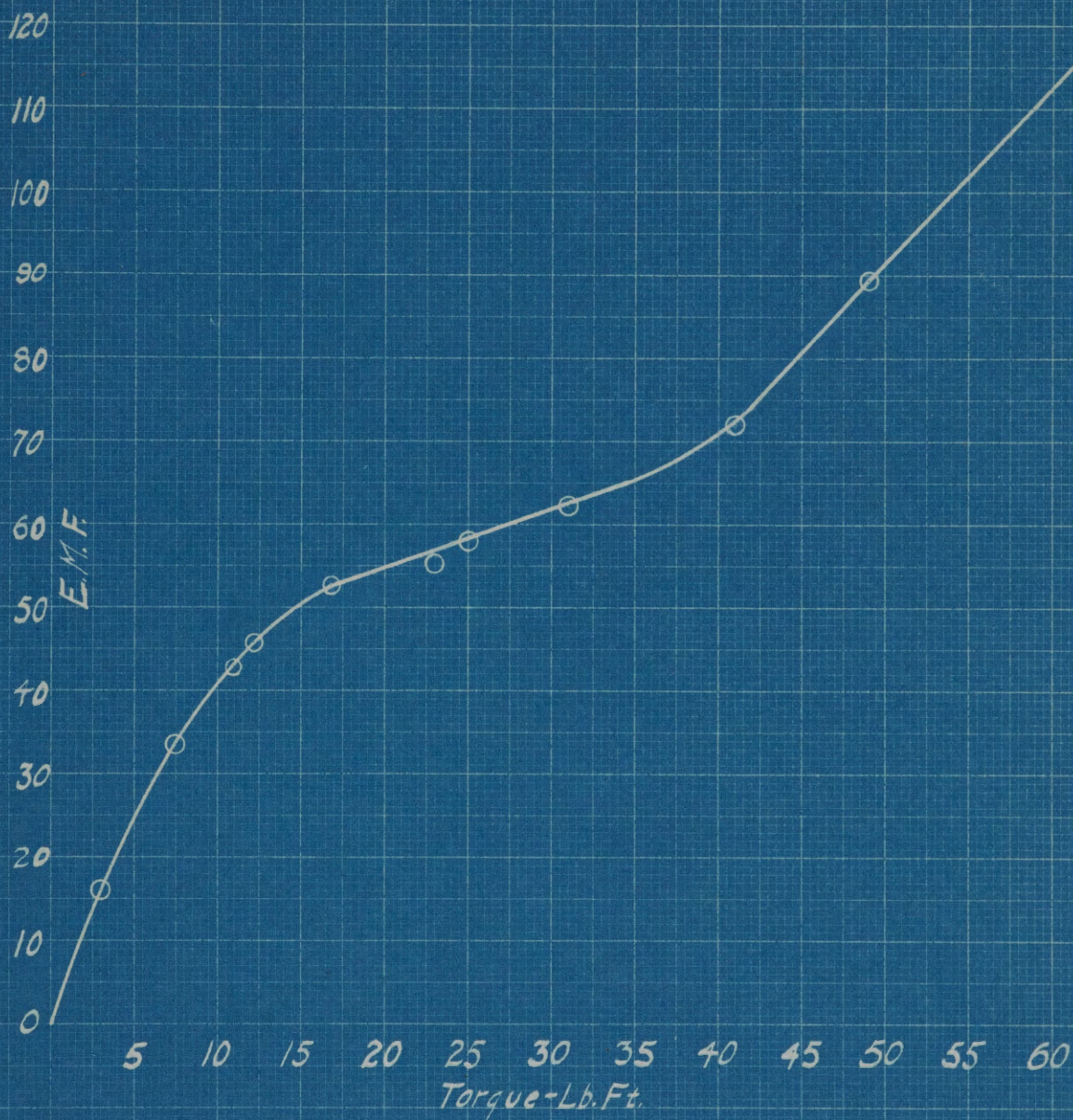
APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

Name _____

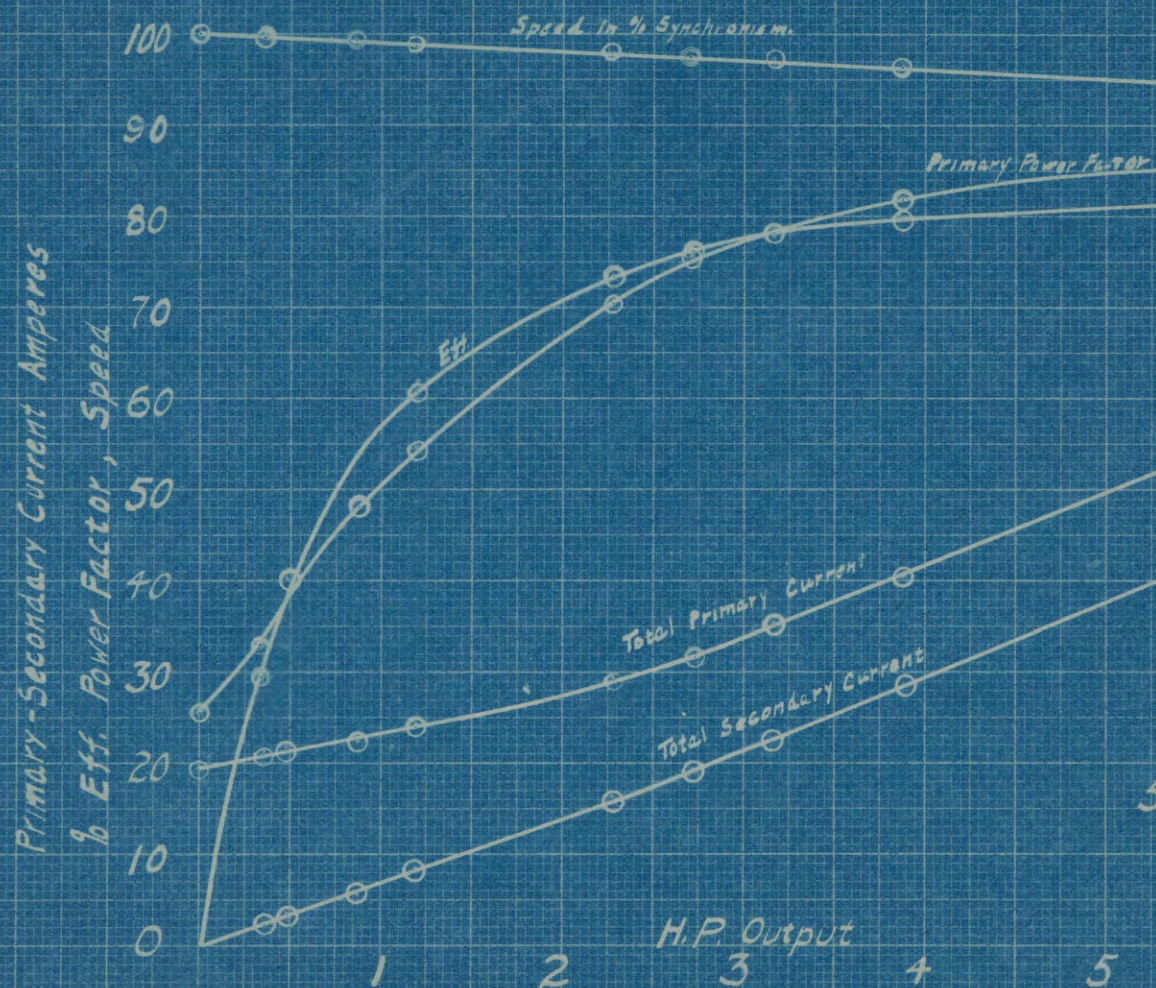
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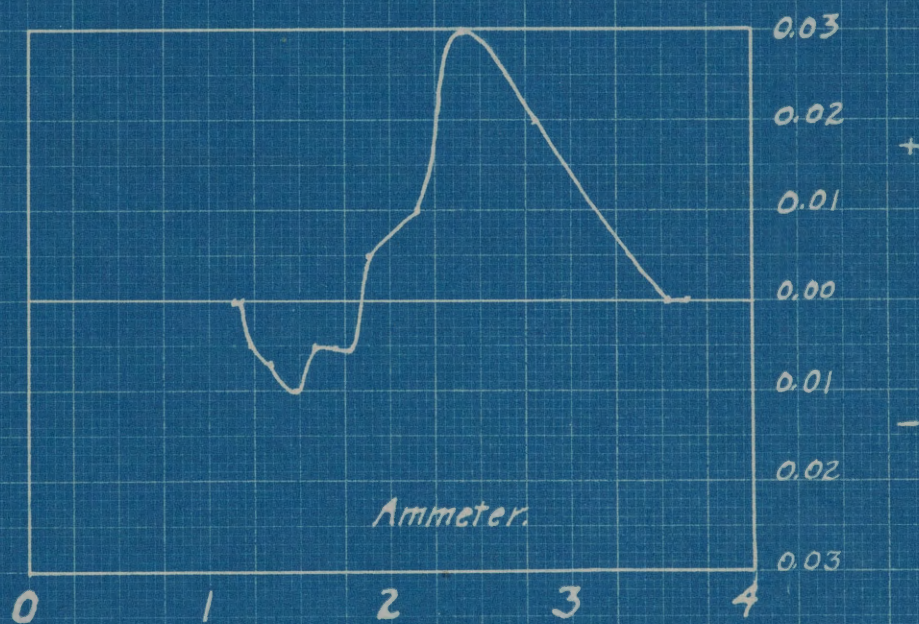
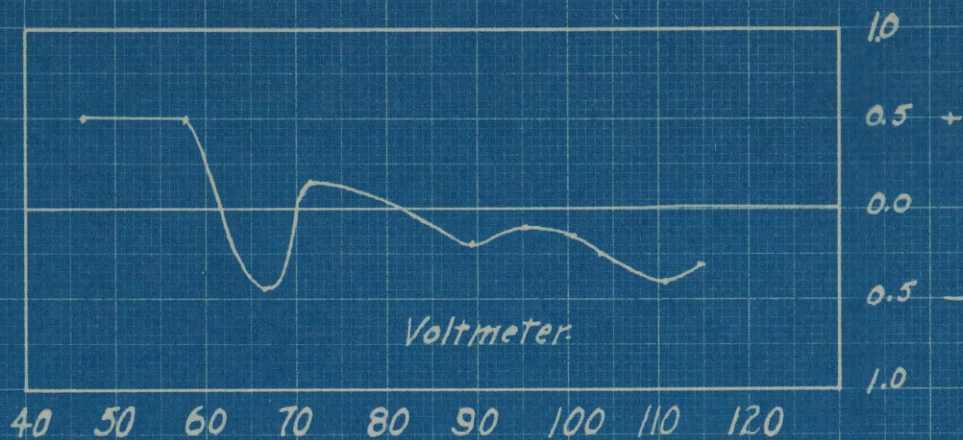
Relation of EMF to Starting Torque.

Plate III



Performance Curves
5 H.P. "Century" Single ϕ
Induction Motor.

Plate IV.

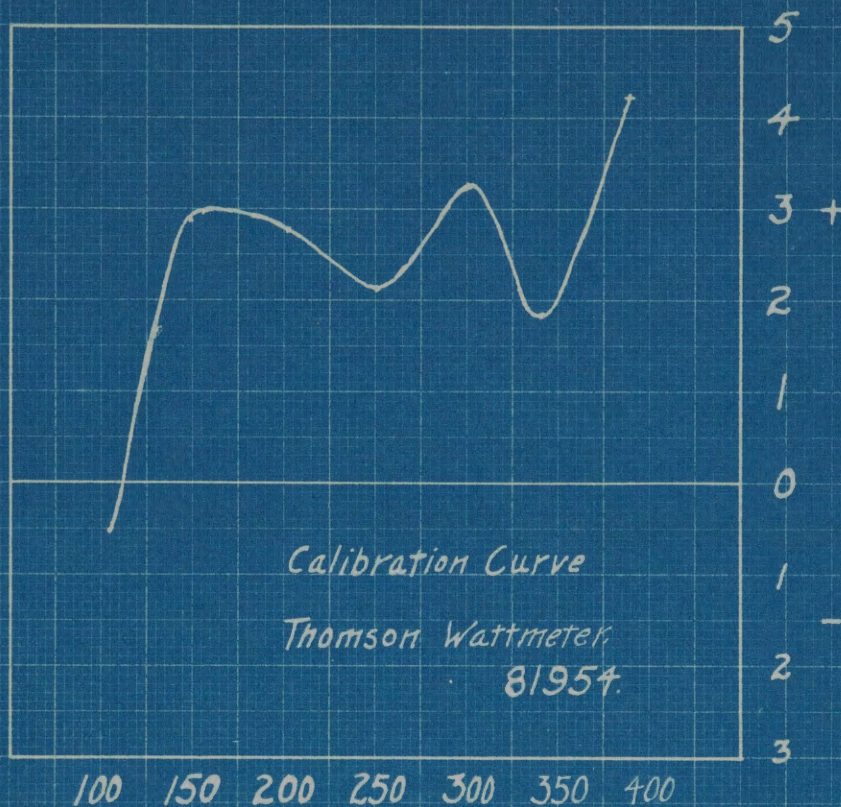


Calibration Curves.

Weston Ammeter 17396.

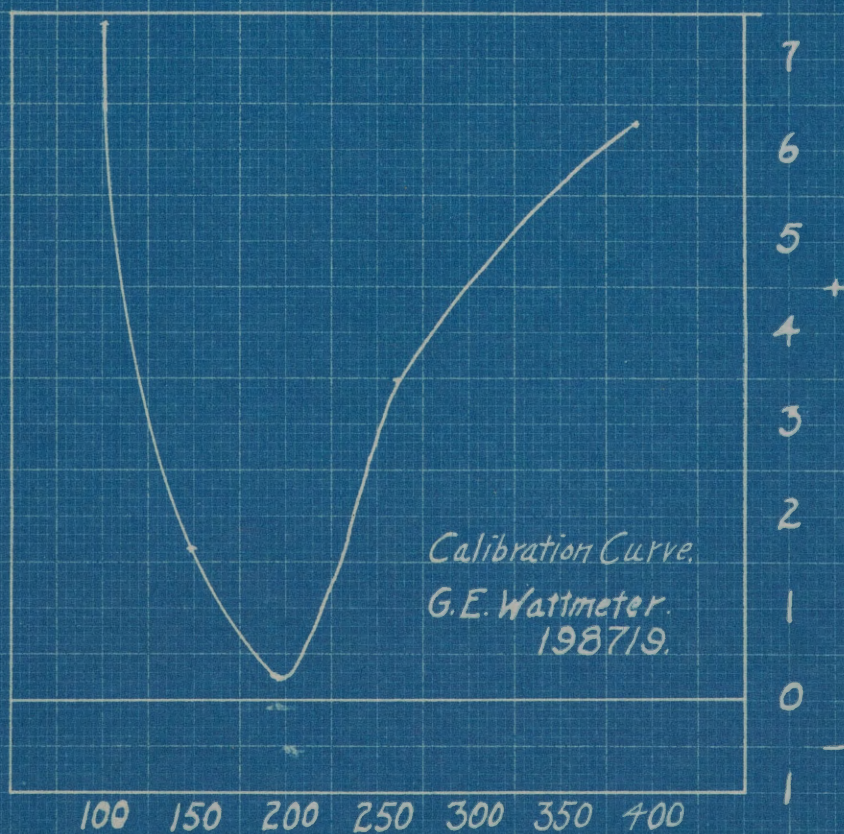
Weston Voltmeter 6202.

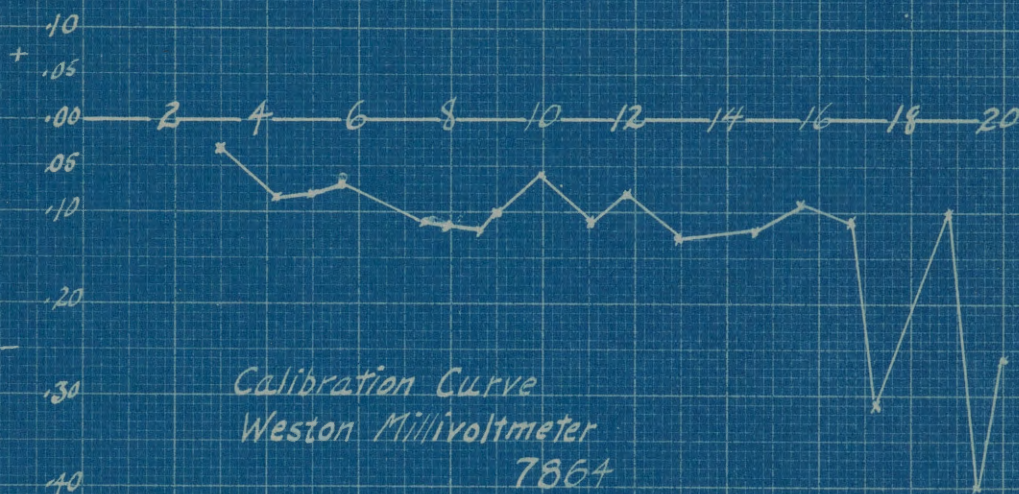
Corrections to be Added.
Plate VI.



Add Corrections

Plate VII.





Add Corrections

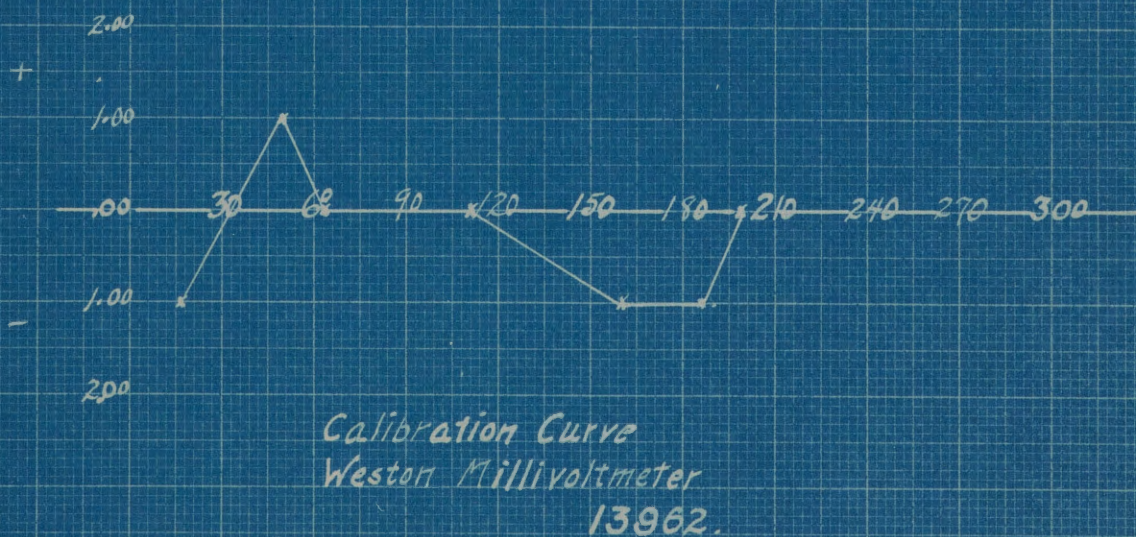


Plate VIII.