A COMPARISON OF BRAKE EFFICIENCY OF INDUCTION MOTORS WITH THE EFFICIENCY AS CALCULATED FROM THE CIRCLE DIAGRAM

Thesis for the Degree of B. S.

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1912

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THESIS

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BY

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MICHIGAN STATE COLLEGE.

1912.

THESIS

This thesis was loaned by

Mr. A. B. Mead

under the date indicated by the department stamp,
to replace the original which was destroyed in the fire
of March 5, 1916.

OBJECT.

The object of this thesis is to compare the efficiencies of various sizes of induction motors as calculated from their efficiencies as determined by prony and rope brakes.

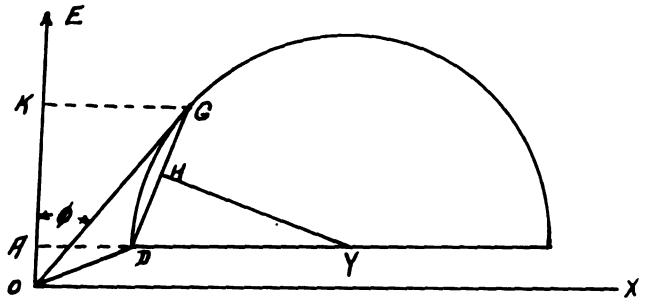
DISCUSSION.

Actual load tests on induction motors, as well as on any other type of electrical machinery, are avoided wherever possible by the average user, since they involve a considerable expenditure of energy and special appliances, if accurate results are required.

Methods have been developed therefore, for predetermining the performance of a machine under actual load conditions. Such a method in application to induction motors is known as the circle diagram. In the construction of the circle diagram the data necessary for predetermining the performance curves of an induction motor are:

1. Ampere and watt input with motor running idle.
2. " " " " " armature locked.
3. Resistance of the stator winding.

In laying out the following diagram, thus:



The axis E equals the impressed voltage, OX the wattless current, OD no load current per phase, OG the short circuit current per phase and D.G. the effective current per phase. The power factor of the motor with armature locked equals Cos ϕ.

Input to motor $= E \times OK \times pl$

Power factor to motor $= \cos \phi = \frac{OK}{OG}$

Stator copper losses $= E \times AK \times pl + r_1 \times OG \times pl$

Input to rotor $= E \times AK \times pl - r_1 \times OG^2 \times pl$

Rotor copper losses $= r_2 \times DG^2 \times pl$

Motor mechanical output $= p \ (E \times AK - r_1 \times OG^2 - r_2 \times DG^2)$

$$\text{Motor efficiency} = \frac{\text{Mechanical output}}{E \times OK \times pl}$$

$$\text{Slip} = \frac{r_2 \times DG^2}{E \times AK - r_1 \times OG^2}$$

$$\text{Torque} = 0.1174 \ \frac{p \times (E \times AK \times pl - r_1 \times OG^2 \times pl}{f}$$

pl = No. of phases.

r_1 = stator resistance per phase.

r_2 = equivalent rotor resistance per phase.

p = No. pairs of poles.

f = frequency.

In each test the generator field was excited from the 125 volt Edison storage battery. While running these tests the voltage was kept constant by an adjustable rheostat in series with the generator field, and the speed of the generator was also kept constant so as to obtain a constant frequency of 60 cycles. The resistance of each stator phase was measured while motor was still warm.

In all the tests the mechanical output was measured with a brake and the electrical input by meters, for various loads from zero to about one and one half rated full load. Instantaneous readings were taken in each case when scale became balanced. All meters were calibrated after the tests were made and the readings corrected.

BRAKES.

The brake used in tests #1 and #2 was of the rope type shown in Fig. 1. Care was taken to have the points of support of the rope in the same vertical plane, tangent to the surface of the pulley, so that the real force and not a component was measured. The brake arm was taken as the distance in feet between the center of the shaft and the center of the rope, which in this case was .247 feet.

The brake arm used in test #3 was of the prony

type, and as shown in Fig. 2, the line AB in feet which is equal to brake arm was kept horizontal and the support on the scale vertical, thus doing away with all component forces. The length of the brake arm on this brake is 1.64 ft.

The pulleys in all three tests were of the water cooling type, fitted to the shafts by means of bushings. The Brake Horse Power from all these tests were figured from the formula $B.H.P. = \frac{2\pi L N W}{33,000}$

where L = the length of the brake arm

N = the number of revolutions per minute and

W = the net weight on scale.

The R.P.M. were measured by a tachometer which was checked before each test by a speed counter.

REFERENCES.

The following authorities were referred to:

Shelton & Mason, pp. 231 - 238.

Karapetoff. Vol. 3. pp. 166 - 174.

Steinmetz - Alternating Current Phenomena. pp. 306 - 310.

American Correspondence School. Vol. 4. pp. 360 - 364.

McAllister's Alternating Motors. pp. 65 - 70.

Dynamometers & Measurements of Power, by Flathers.

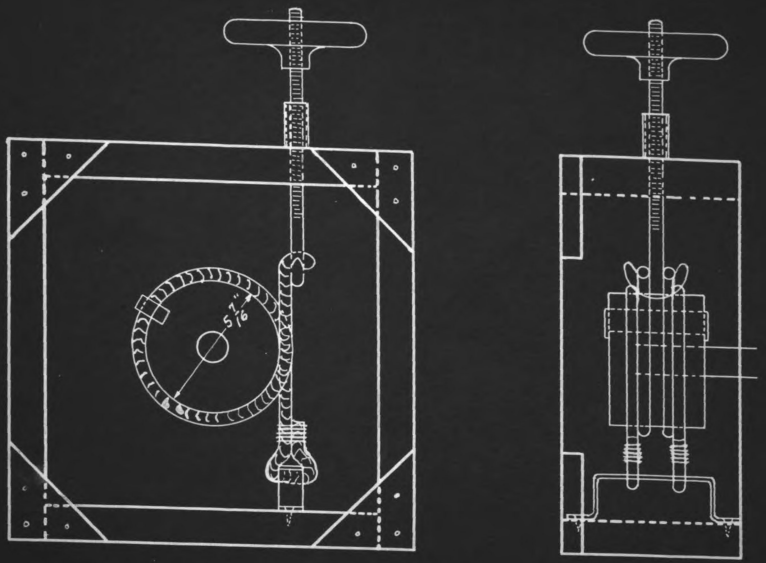


Fig 1.

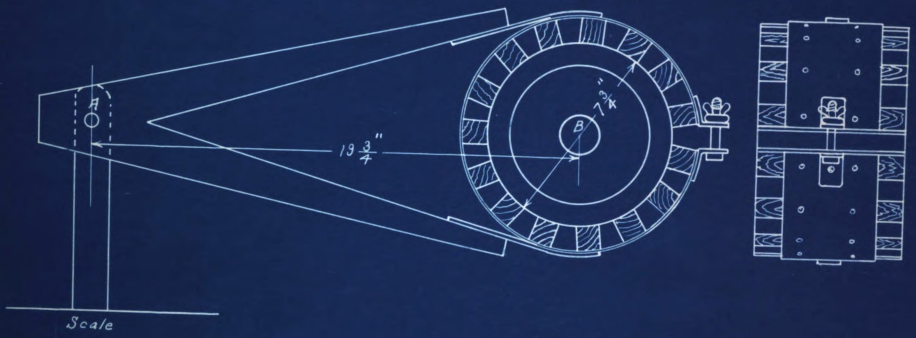


Fig 2.

CONCLUSION.

In each case care was taken to keep the pulley in the middle of the rope brake frame, for if it is above or below the middle, the error is increased when the line joining the supports of the rope is not tangent to surface of pulley.

As shown in the efficiency curves for test #1, the brake is not to be depended upon for readings of light loads. Best results were obtained from the prony brake as are shown by the efficiency curves in test #3, the brake being more sensitive and a more accurate balance obtained.

It was found that due to vibration, stiffness of the rope, high speed of motor and difficulty of keeping the points of support of rope in same plane tangent to pulley, that this method of testing a motor is not as desirable as a test with circle diagram.

TEST #1.

The motor used in this test was of the following description:- 2 H.P., 220 volts, 4 poles, 2 phase, 60 cycle, 1800 R.P.M., General Electric induction motor, having a wound rotor with full load current of 5 amperes. The factory number is 71406, Type 10, Class A-2-1800, Form K.

The mechanical output was measured by a rope brake shown in Fig. 1, and the current was taken from a 125 volt Rotary Converter with the voltage stepped up to 220 by means of auto transformers.

220 VOLT INDUCTION MOTOR

2 H.P. 2 PHASE 1800 R.P.M. 4 POLE

STRAY POWER READINGS

AMPS	WATTS	VOLTS	SPEED	
2.2	8.2	220	1800	RUNNING LIGHT
6.75	205.2	58	—	ROTOR LOCKED

BRAKE TEST READINGS

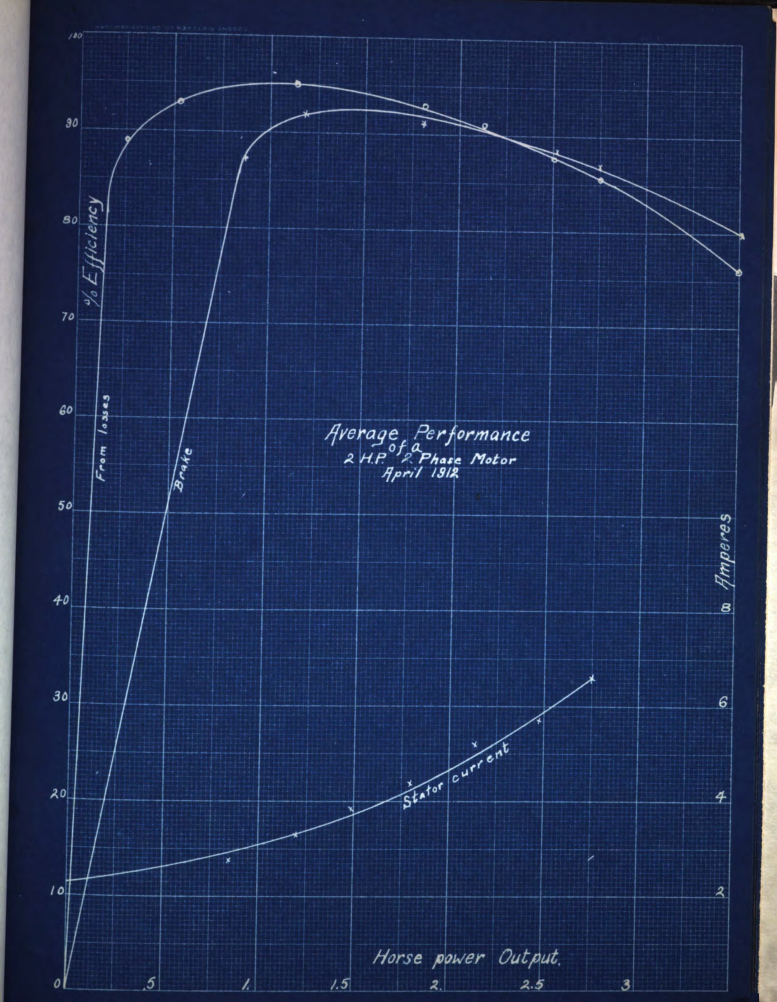
AMPS	WATTS	VOLTS	SPEED	LOAD	H.P.	% EFF.
2.30	47	220	1800	0	0.00	0.0
2.75	360	"	1785	10	084	86.7
3.23	475	"	1782	14	1.17	92.0
3.84	608	"	1760	18	1.49	91.4
4.37	742	"	1750	22	1.81	91.0
5.20	870	"	1740	26	2.12	91.0
560	965	"	1730	30	2.44	94.0
660	1170	"	1712	34	2.74	87.0

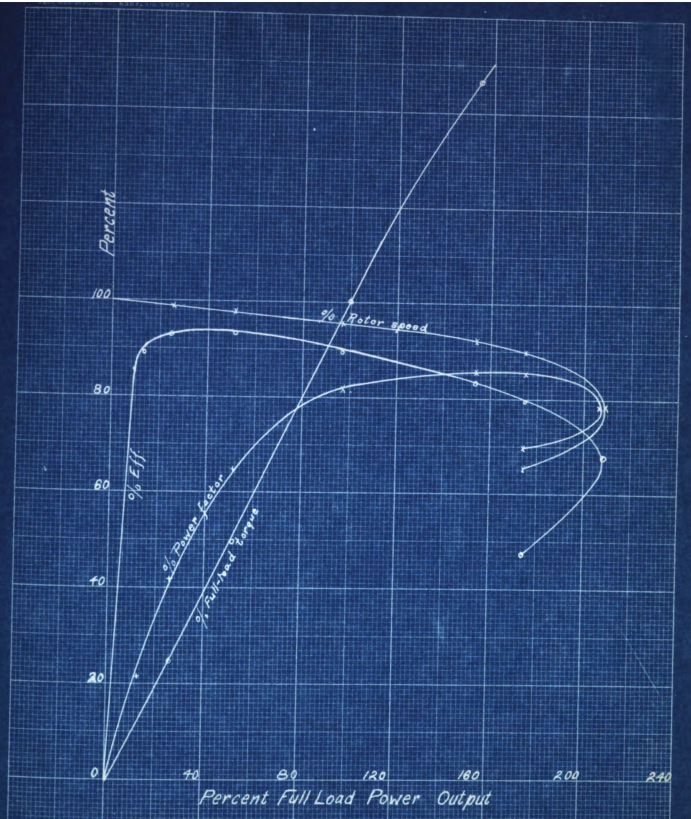
ROTOR RESISTANCE = 2.08 OHMS

EQUIALENT STATOR RESISTANCE = 2.24 OHMS

COMPUTATIONS FROM CIRCLE DIAGRAM

PT.	POWER FACTOR	WATTS OUTPUT	EFF. %	TOTAL H.P.	% FULL LOAD	TORQUE	% SLIP	% FULL LOAD TORQUE
1.	21.7	187	89.0	0.25	12.1	1.47	.48	11.6
2.	41.6	391	93.0	0.52	25.4	3.10	1.13	24.5
3.	64.5	782	93.0	1.05	50.7	6.26	2.24	49.5
4.	81.5	1508	89.7	2.02	97.6	12.35	4.52	97.5
5.	82.0	1542	89.4	2.07	100.0	12.65	4.65	100.0
6.	85.0	2374	83.0	3.18	153.5	18.55	8.46	146.7
7.	74.9	2684	79.8	3.60	174.0	23.40	10.40	185.0
8.	78.0	3215	63.7	—	208.0	12.35	21.20	97.5
9.	69.7	2680	46.8	—	173.5	32.30	35.10	25.5


Average Performance
of a
2 H.P. 2 Phase Motor
April 1912
% Efficiency
From losses
Brake
Amperes
Stator current
Horse power Output.
100
90
80
70
60
50
40
30
20
10
0
8
6
4
2
.5
1.
1.5
2.
2.5
3

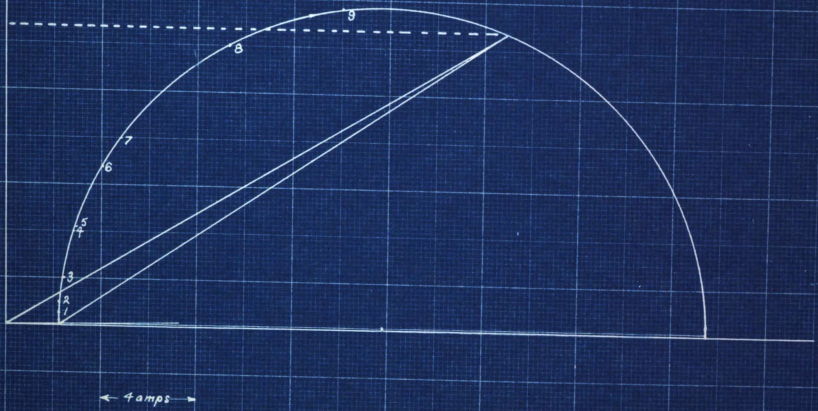


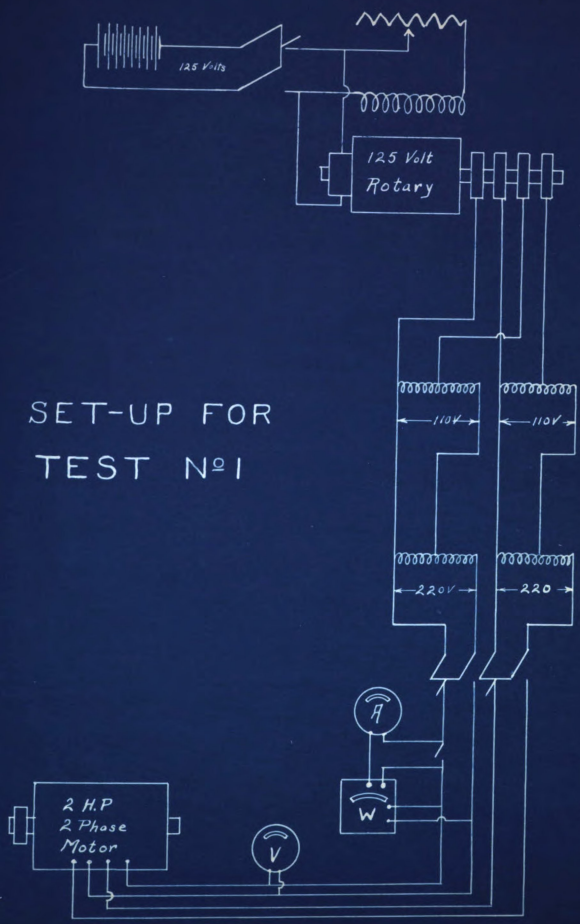
Performance Curves From Circle Diagram

2 H.P. 2 Phase Motor

April 1912

Circle Diagram For 2 H.P. 2 Phase Motor





SET-UP FOR TEST Nº 1

TEST #2.

The test was made on an induction motor manufactured by the General Electric Co. It is a 3 phase, 5 H.P., 220 volts machine running at 1200 R.P.M. and draws 13.2 amperes of 60 cycle current at full load. The factory number is 183030, Type KT-6-5A, Form C.

A rope brake shown in Fig. 1 was used to measure the mechanical output. A 2200 volt alternator furnished the current, and by means of transformers was changed from 2 phase, 2200 volts to 3 phase, 220 volts.

The three phases were then connected to the secondaries of three transformers connected Y. This Y connection forms a balanced system so that the wattmeter, as shown in set-up, measures 1/3 of total input to the motor.

220 VOLT INDUCTION MOTOR

5 H.P., 3 PHASE, 1200 R.P.M. 6 POLE.

STRAY POWER

AMPS	WATTS	VOLTS	SPEED	
1.595	25	220.0	1200	RUNNING LIGHT
24.250	540	82.8	—	ROTOR LOCKED

BRAKE TEST READINGS.

AMPS.	WATTS	VOLTS	SPEED	LOAD	H.P.	EFF.
5.55	62.5	220	1190	0.0	—	—
5.55	137.0	"	1187	5.5	0.35	50.8
6.00	250.0	"	1180	14.5	0.77	76.7
6.50	337.0	"	1175	22.5	1.19	88.0
7.00	450.0	"	1170	30.5	1.61	89.0
7.80	535.0	"	1165	38.5	2.02	94.1
8.50	630.0	"	1160	46.5	2.43	96.0
9.25	947.0	"	1155	54.5	2.84	94.0
11.35	1030.0	"	1145	72.5	3.80	94.0
12.10	1190.0	"	1150	82.5	4.45	92.6
13.20	1375.0	"	1135	92.5	4.93	89.0
14.75	1470.0	"	1120	102.5	5.40	91.0
15.80	1665.0	"	1115	112.5	5.90	88.0
17.85	1800.0	"	1107	122.5	6.36	86.0
20.00	2025.0	"	1095	132.5	6.90	83.8

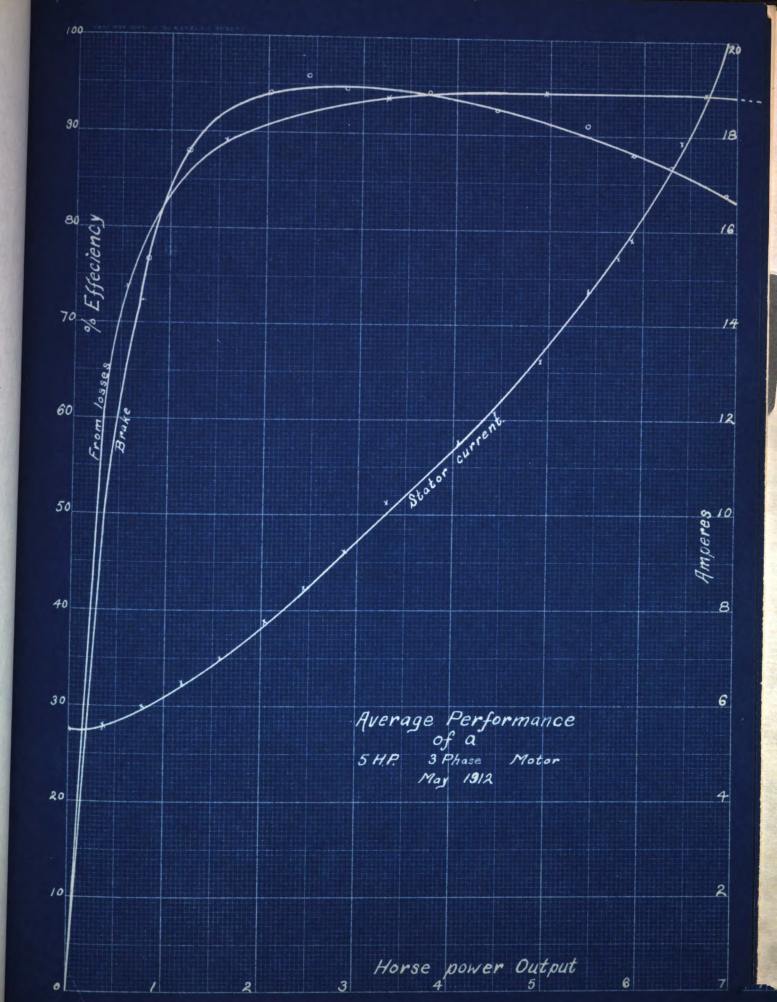
STATOR RESISTANCE = .49 OHMS

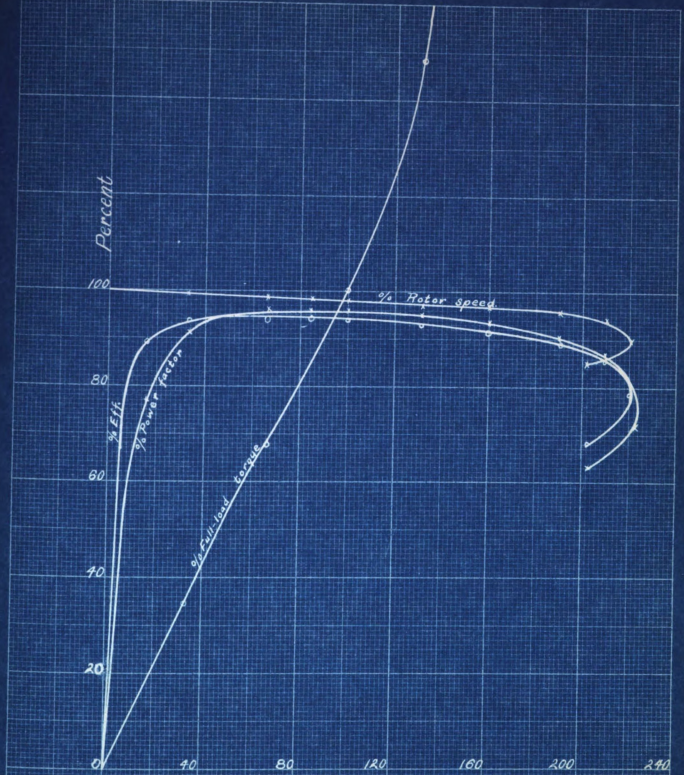
EQUIVALENT ROTOR RESISTANCE = .347 OHMS.

COMPUTATIONS

FROM CIRCLE DIAGRAM

PT.	POWER FACTOR	WATTS OUTPUT	EFF. %	TOTAL H.P	% FULL LOAD	TORQUE	% SLIP	% FULL LOAD TORQUE
1.	44.4	391	74.0	0.59	5.9	2.3	0.09	5.2
2.	76.9	1175	88.9	1.57	15.8	6.9	0.28	15.6
3.	90.9	2461	93.2	3.30	33.3	14.6	0.64	33.0
4.	94.7	3728	94.0	4.98	50.4	22.1	0.96	50.0
5.	94.0	4989	94.4	6.66	66.6	29.7	1.29	67.0
6.	94.3	6206	94.0	8.28	83.7	37.0	1.64	83.5
7.	94.5	7396	93.4	9.90	100.0	44.0	2.06	100.0
8.	94.0	9731	92.2	13.01	131.5	65.5	2.83	148.5
9.	92.0	11904	91.0	15.80	159.8	71.5	3.66	161.7
10.	89.5	14046	89.4	18.80	190.0	86.0	4.70	194.0
11.	86.0	15582	85.0	20.80	210.0	97.2	6.02	220.0
12.	72.0	17178	78.0	23.00	232.2	110.0	11.30	248.0
13	63.4	15030	68.0	20.10	203.1	104.0	15.10	235.0

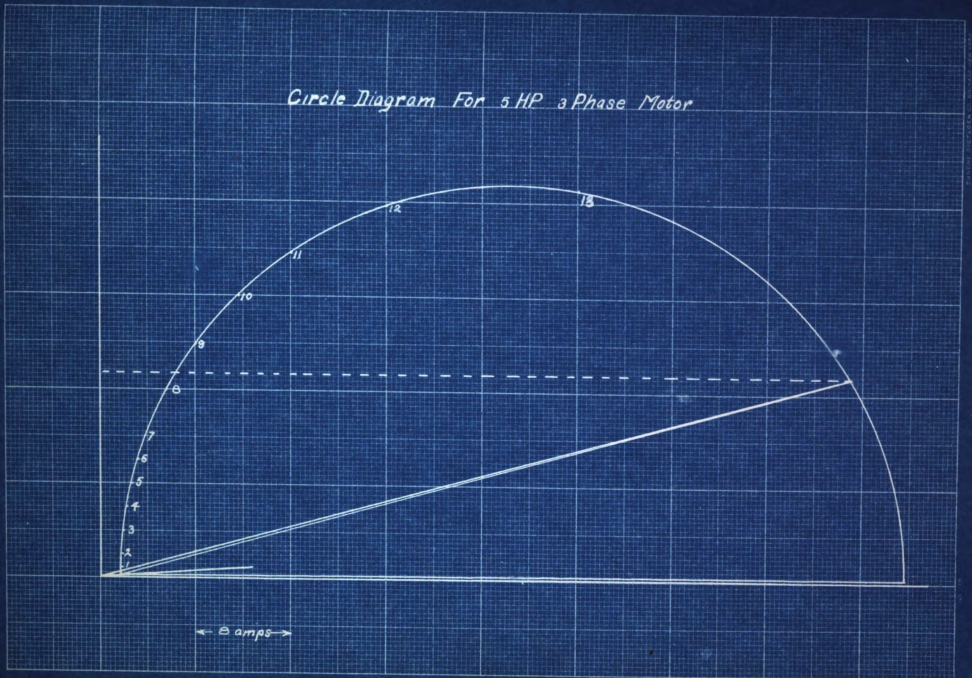

% Efficiency
From losses
Brake
Stator current
Amperes
Horse power Output
Average Performance
of a
5 HP. 3 Phaze Motor
May 1912
100
90
80
70
60
50
40
30
20
10
0
20
18
16
14
12
10
8
6
4
2
1
2
3
4
5
6
7

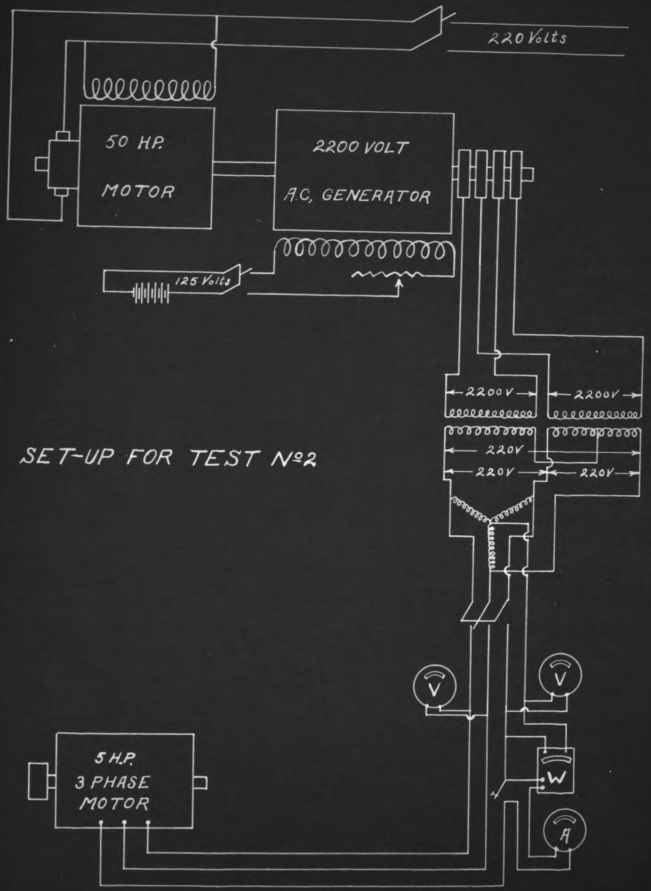


Performance Curves From Circle Diagram

5 H.P. 3 Phase Motor

May 1912


Circle Diagram For 5 HP 3 Phase Motor
12
13
11
10
9
8
7
6
5
4
3
2
1
← 2 amps →


220 Volts
50 H.P.
MOTOR
2200 VOLT
A.C. GENERATOR
125 Volts
2200 V
2200 V
220 V
220 V
220 V
SET-UP FOR TEST Nº2
V
V
W
A
5 H.P.
3 PHASE
MOTOR

TEST #3.

The machine used in this test was built by the Westinghouse Electric Co. It is a 2 phase, 10 H.P., 200 volts, induction motor, speed 1200 R.P.M. The factory number is 34046.

A prony brake was used to measure the mechanical output. The current for this motor was taken from a 2200 volt alternator and stepped down to 220 volts by means of transformers. The primary in this machine was the rotor instead of the stator.

200 VOLT INDUCTION MOTOR

10 H.P. 2 PHASE 1200 R.P.M.

STRAY POWER READINGS

AMPS	WATTS	VOLTS	SPEED	
14.7	470	200	1192	RUNNING LIGHT
25.0	590	43	——	ROTOR LOCKED

BRAKE TEST READINGS

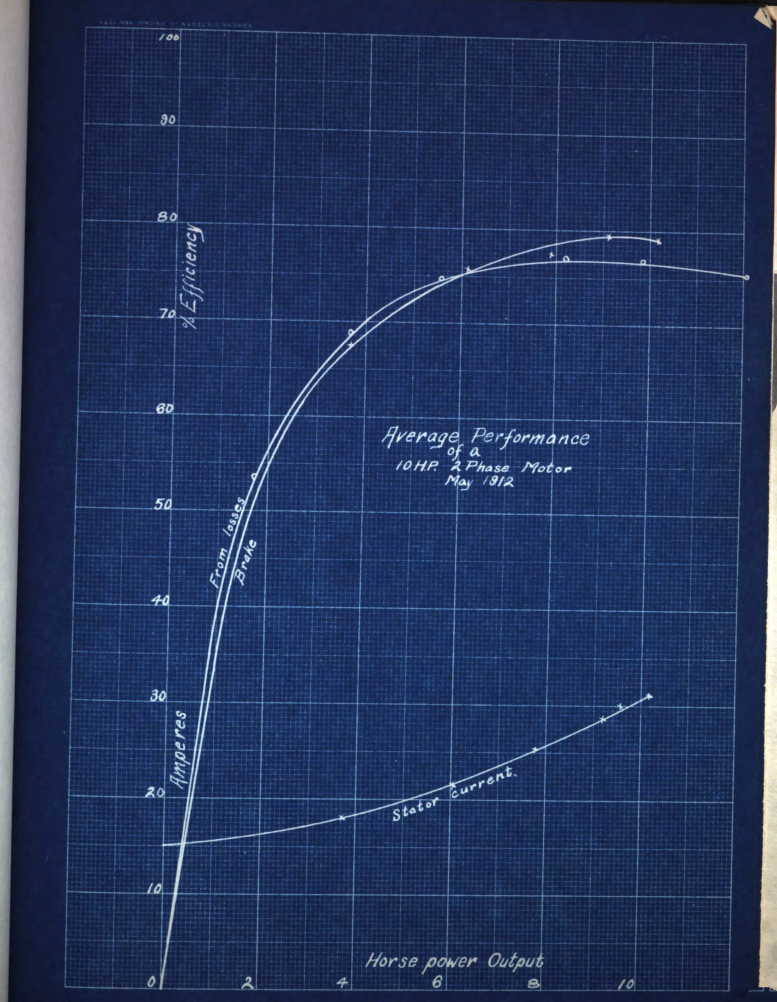
AMPS	WATTS	VOLTS	SPEED	LOAD	H.P. OUTPUT	H.P. INPUT	% EFF.
15.0	600	200	1190	0.0	0.0	1.6	0.0
18.0	2050	"	1185	10.0	3.7	5.5	67.5
21.5	3000	"	1172	16.5	6.1	8.0	75.3
25.5	3800	"	1178	21.5	7.9	10.2	77.8
28.5	4300	"	1155	25.2	9.1	11.5	79.4
30.0	4575	"	1145	26.5	9.5	12.2	77.7
31.0	4800	"	1140	28.5	10.2	12.8	79.3

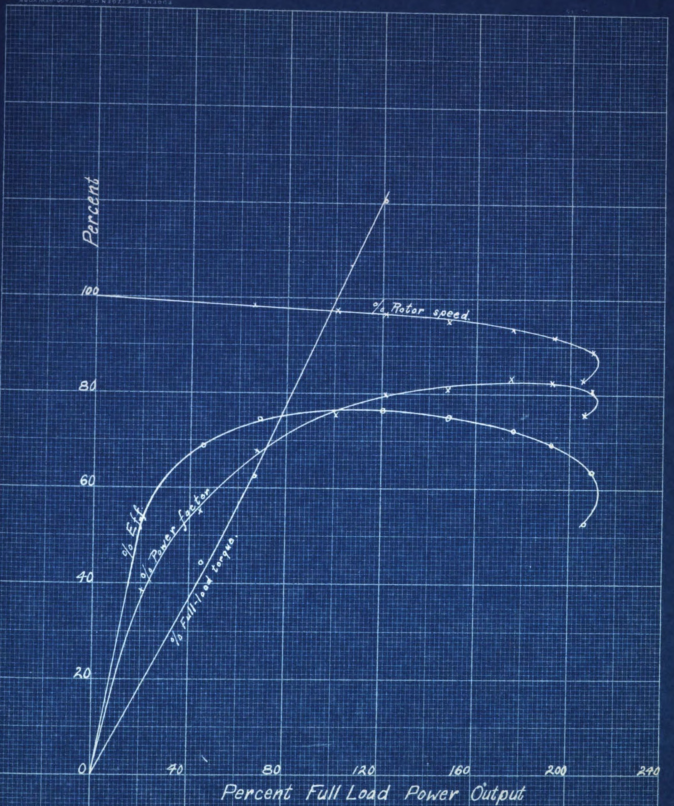
ROTOR RESISTANCE = .64 OHMS

EQUIVALENT STATOR RESISTANCE = .273 OHMS

COMPUTATIONS FROM CIRCLE DIAGRAM

PT.	POWER FACTOR	WATTS OUTPUT	EFF.%	TOTAL HP	% FULL LOAD	TORQUE	% SLIP	% FULL LOAD TORQUE
1.	38.5	1279	53.2	1.7	21	7.5	0.6	20
2.	55.6	2753	68.7	3.7	45	16.4	1.1	44
3.	67.4	4172	74.5	5.6	68	21.1	1.7	57
4.	76.4	6145	76.7	8.2	100	37.1	2.8	100
5.	79.5	7368	76.7	9.8	120	44.7	3.4	121
6	81.5	9027	75.2	12.1	147	55.6	4.6	150
7	83.5	10821	72.7	14.5	176	67.6	6.2	182
8	83.0	11762	70.0	15.7	192	74.7	7.5	200
9	81.2	12842	64.2	17.2	209	84.1	10.4	227
10	76.4	12760	53.5	17.1	206	89.5	16.7	241

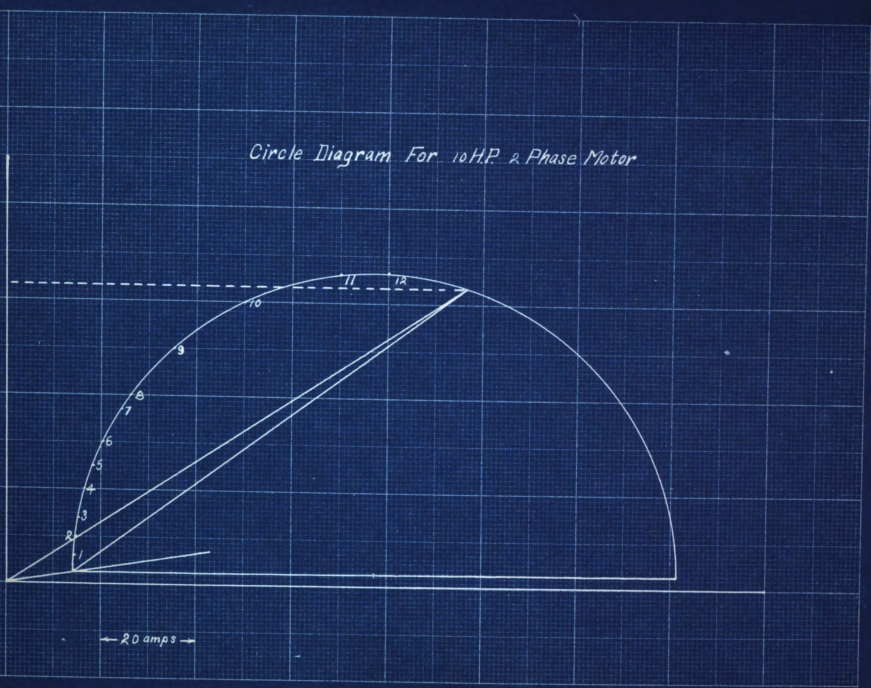

% Efficiency
Amperes
Average Performance
of a
10 HP. 2 Phase Motor
May 1912
From losses
Brake
Stator current.
Horse power Output
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10

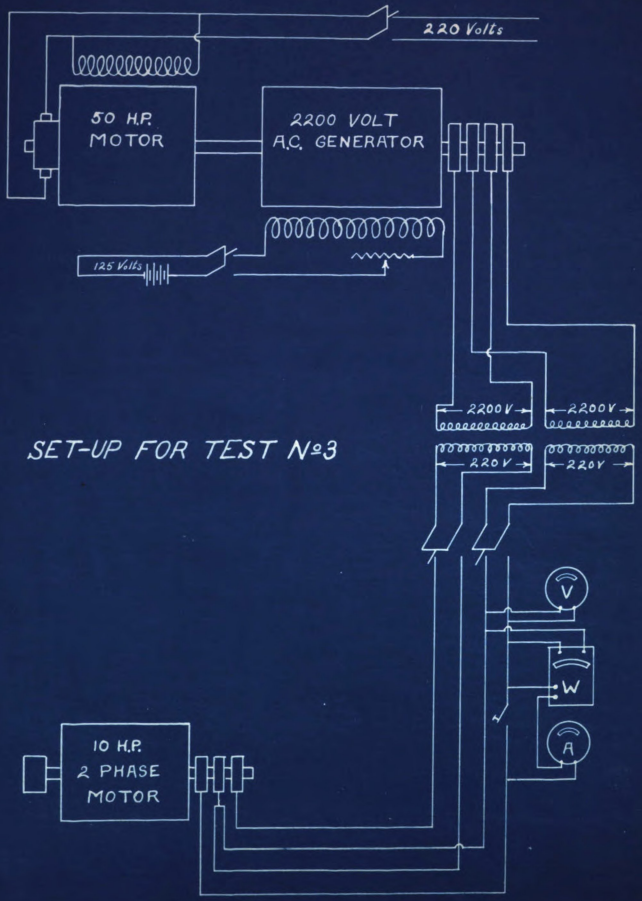


Performance Curves From Circle Diagram

10 H.P. 2 Phase Motor

May 1912


Circle Diagram For 10 H.P. 2 Phase Motor
11
12
10
9
8
7
6
5
4
3
2
1
20 amps



SET-UP FOR TEST No3