Thesis

Presented for the degree

of

Bachelor of Science in Electrical Engineering

by

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Subject.

The Study of the Performance of an Induction Motor.

1916.

The Induction Motor.

The machine upon which this Performance Study was made was built by the Westinghouse Electric Co. of East Pittsburgh, Pa.

The Manufacturer's Rating.

5 H. P., 29 Ampere, 100 Volt, 60 Cycle, and 1700 R. R. M.

The Performance Study.

The ideal performance of an induction motor is that performance which the circle diagram of the motor indicates that the motor should give.

This study of performance consists of a comparison of the results obtained by actually loading the motor, with the results predicted for the motor by the circle diagram of the motor.

To make this performance study the circle diagram of the motor was constructed, and the motor was actually loaded by means of a prony brake.

Curves plotted from the data obtained by actually loading the motor and from the data obtained by constructing the circle diagram of the motor form the comparative basis for the performance study of the motor.

This performance study ranges from 71 percent rated full load to 136 percent rated full load.

The Circle Diagram.

To construct the circle diagram of the motor it is necessary to have the no load data of the motor, the locked load data of the motor, and the average resistance of the stator windings.

The No Load Test.

This test is run with the voltage at the motor's rated voltage, and the current intake has the frequency rated for the motor. The data taken are the ampere and watt input of the motor. These data determine one end of the diameter of the circle diagram and also the constant losses (Bore) of the motor.

The Locked Load Test.

The current intake has the frequency rated for the motor. The rotor is locked. The data taken are the impressed voltage, the current intake, and the watt intake. These data determine another point on the circle diagram and also are a factor in determining the equivalent resistance of the rotor.

The Stator Resistance.

D. C. current is applied to the mains. The data taken are the current flowing and the impressed voltage. These data determine the apparent resistance of the stator, and also are a factor in determining the equivalent resistance of the rotor.

The Prony Brake Test.

The current intake of the motor was at the rated voltage and frequency of the motor.

The usual prony brake test was run on the motor. The load was at one end of the brake and at the other end there was a spring compensating balance which automatically kept the load adjusted.

The data taken were the watt intake of the motor, the current intake of the motor, the rotor speed, the lengths of the brake arms, and the loads on the brake arms.

The following pages contain the data necessary for the construction of the circle diagram of the motor and the data obtained from actually loading the motor.

Circle Diagram.

No Load Data

$E\dot{I}\cos\theta$	$E\ddot{I}\cos\theta$	I	
1.5	-Q07	2.49	current ratio 1:5
1.65	-0.07	2.50	volts 100
1.65	-0.07	2.53	

Locked Load

$E\dot{I}\cos\theta$	$E\ddot{I}\cos\theta$	I	
1.39	-0.05	4.32	current ratio 1:10
1.39	-0.05	4.28	volts 40
1.39	-0.05	4.24	

Apparent Resistance of Stator

by testing set.

R = 0.238 R = 0.236 R = 0.24

avg. R = 0.238

Prony Brake Test.

Current ratio 1:5, Voltage 100, and Frequency 60.

$\dot{E}\dot{I}\cos\theta$	$\ddot{E}\ddot{I}\cos\theta$	I	Rotor R. P. M.	T arm P	S. arm W
7.74	3.95	7.55	1600	5.5	25
8.38	4.2	7.95	1600	5.5	25
8.05	3.94	7.6	1602	5.5	25
7.24	3.65	7.24	1628	5.5	23
7.15	3.48	7.15	1625	5.375	23
6.95	3.55	6.95	1625	5.375	23
6.75	3.34	6.58	1638	4.5	21
6.78	3.55	6.68	1636	4.85	21
7.15	3.62	6.9	1641	4.25	21
5.6	2.6	5.62	1680	4.5	18
5.3	2.5	5.4	1678	4.375	18
5.51	2.61	5.52	1670	4.5	18
5.1	2.42	5.2	1690	3.5	16
5.39	2.47	5.38	1688	3.5	16
5.24	2.40	5.32	1683	3.5	16
3.85	1.64	4.1	1694	3.	12
"	1.65	4.02	1698	3.	12
4.1	"	4.22	1700	3.	12

Wattmeter 14304

Ammeter 42221

Voltmeter 6202

Reading in hecto watts.

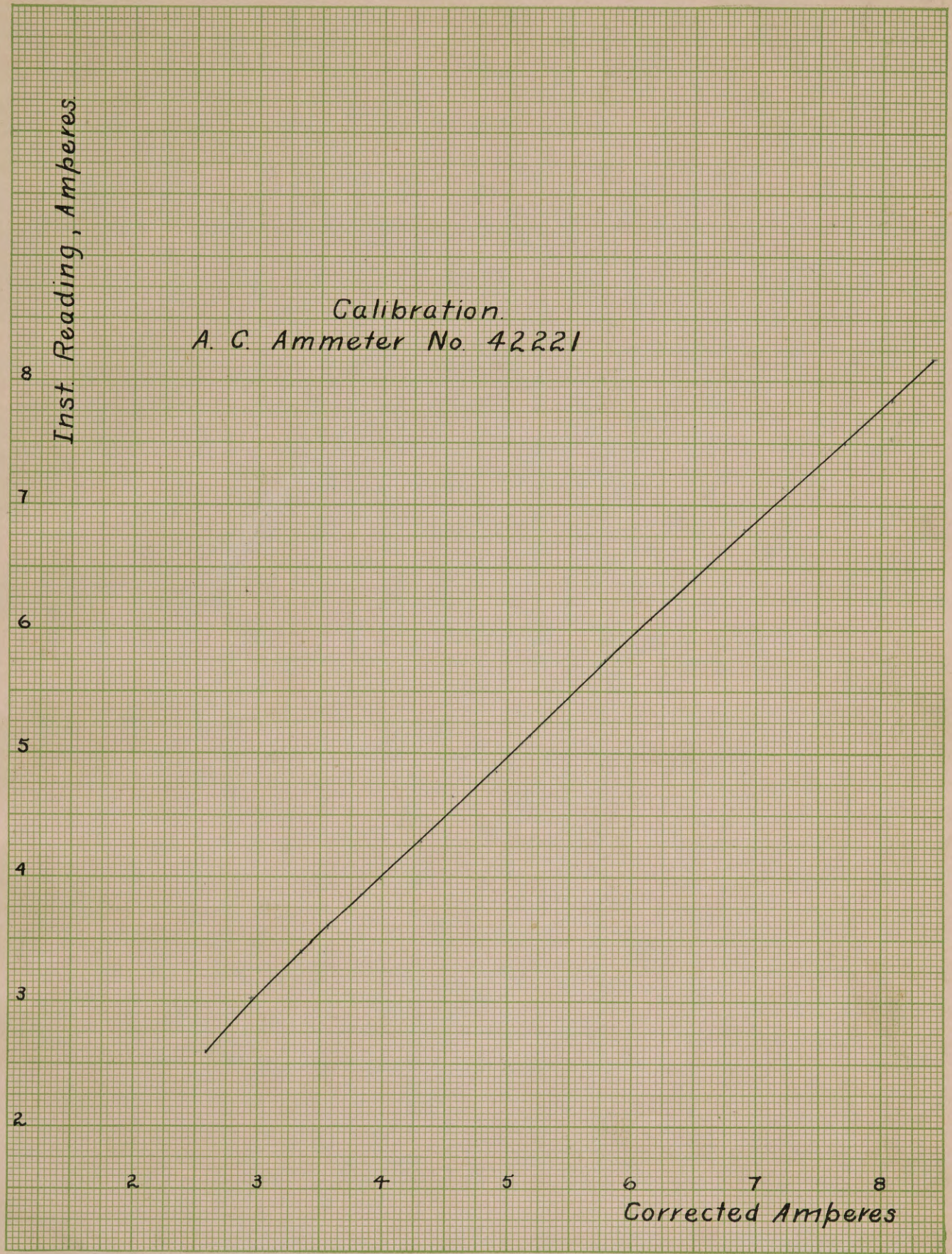
Calibration.

No instrument, no matter how accurate or how carefully constructed, does accurately that which it was constructed for, it is therefore necessary that all instruments be calibrated so as to eliminate their errors.

The following pages contain the data for the calibration of Voltmeter No. 6203, A. C. Ammeter No. 42231, and Wattmeter No. 43104.

Calibration of A. C. Ammeter No. 42321.

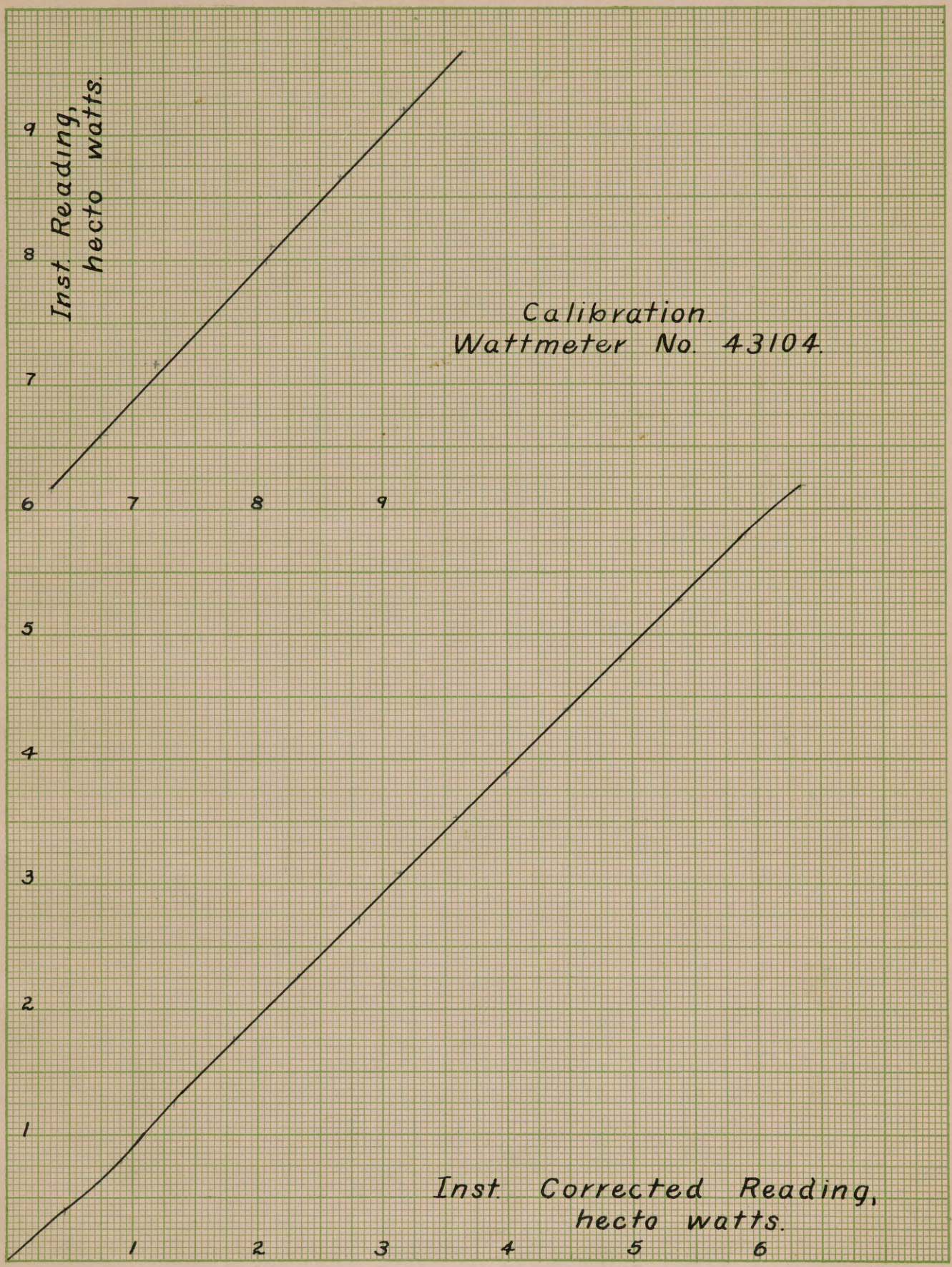
Amperes A. C. Ammeter	Cm. Multicellular	Cm. Multicellular	Amperes D. C. Standard	Corrected A. C. Ammeter
3.98	64.4	143.7	8.34	3.98
4.28	69.1	135.4	7.85	4.31
4.61	73.	126.8	7.4	4.56
4.85	78.9	116.8	6.88	4.92
5.15	84.1	110.	6.51	5.18
5.44	89.7	103.5	6.22	5.48
5.75	95.7	96.	5.83	5.78
6.1	103.	90.2	5.53	6.16
6.4	109.5	94.1	5.72	6.5
6.8	117.5	84.5	5.2	6.9
7.15	124.5	77.	4.8	7.3
7.5	132.5	73.6	4.58	7.7
7.85	139.5	67.	4.18	8.07
8.61	152.	63.2	3.88	
8.18	144.7	120.8	7.08	8.4
2.6	70.8	133.	4.39	2.58
2.82	77.8	124.3	4.14	2.77
3.03	83.	112.4	3.91	2.95
3.4	96.6	106.	3.61	3.35
3.62	104.6	96.3	3.32	3.57
3.87	114.	85.	3.	3.85
4.04	119.5	77.7	2.75	4.01
4.4	132.8	69.2	2.47	4.38


Calibration
A. C. Ammeter No. 42221
Inst. Reading, Amperes
8
7
6
5
4
3
2
2
3
4
5
6
7
8
Corrected Amperes

Calibration of Wattmeter No. 43104.

The impressed voltage (calibrated) was constant at 100.

I	E I cos θ	Correct reading
8.09	8.	8.09
7.66	7.9	7.66
7.19	7.18	7.19
6.75	6.6	6.75
6.35	6.18	6.35
5.9	5.8	5.9
5.38	5.28	5.38
4.91	4.8	4.91
4.48	4.4	4.48
3.98	3.88	3.98
3.58	3.53	3.58
3.14	3.09	3.14
2.76	2.7	2.76
2.32	2.27	2.32
1.8	1.75	1.8
1.33	1.25	1.33
0.91	0.8	0.91
0.46	0.4	0.46
10.58	10.68	10.58
10.1	10.3	10.1
9.64	9.65	9.64
9.18	9.2	9.18
8.67	8.68	8.67
8.11	8.11	8.11


Inst. Reading, hecto watts.
9
8
7
6
7
8
9
Calibration.
Wattmeter No. 43104.
5
4
3
2
1
Inst. Corrected Reading, hecto watts.
1
2
3
4
5
6

Calibration.

The alternating current voltmeter No. 6202 was calibrated at only two points, 40 volts and 100 volts. The 40 volts being that at which the current was supplied to the locked motor, and 100 volts being the voltage at which the motor was run, as it was the motor's rated voltage. At the voltages 40 and 100 the voltmeter No. 6202 indicated correctly.

Circle Diagram Data (Insts. Calibrated)

Current Ratio 1:5 , Voltage 100, and Frequency 60.

No Load Data.

$E\dot{I}'\cos\theta$	$E\ddot{I}\cos\theta$	I
1.56	-0.81	2.48
1.7	-0.81	2.49
1.7	-0.81	2.51

Current Ratio 1:10, Voltage 40, and Frequency 60.

Locked Load Data.

$E\dot{I}\cos\theta$	$E\ddot{I}\cos\theta$	I
1.42	-0.05	4.32
1.38	-.0 5	4.28
1.38	-0.05	4.24

Prony Brake Test.

(inst. calibrated)

$\dot{E}\dot{I}\cos\theta$	$\dot{E}\dot{I}\cos\theta$	I	Rator Slip	L. arm P #	S. arm W #
7.73	4.03	7.75	200	5.5	25
8.38	4.3	8.25	198	5.5	25
8.05	4.02	7.8	200	5.5	25
7.22	3.7	7.34	172	5.5	23
7.18	3.53	7.2	175	5.375	23
7.02	3.6	7.2	175	5.375	23
6.85	3.4	6.7	162	4.25	21
6.9	3.6	6.8	164	4.25	21
7.2	3.68	7.	159	4.5	21
5.7	2.63	5.66	121	4.5	18
5.4	2.53	5.45	122	4.375	18
5.61	2.64	5.57	130	4.5	18
5.2	2.45	5.22	110	3.5	16
5.5	2.51	5.42	112	3.5	16
5.35	2.43	5.35	117	3.5	16
4.22	1.6	4.17	106	3.	12
3.92	1.7	4.	102	3.	12
4.18	1.7	4.2	100	3.	12

Wattmeter No 14304
Ammeter No 42221
Voltmeter No 6202

The following pages contain the prony brake test results and the circle diagram results, also the performance curves of the motor and the circle diagram of the motor.

Prony Brake Test Results.

Long Arm 2 ft.				Short arm 1.25 ft.	
Delivered K.W.	Input K.W.	Efficiency	Torque Syn. K.W.	Slip	Cos Θ
	W 25#,		P 5.5#,	I 39.665 Amperes	
4.5	6.484	0.74	5.06	0.111	0.859
	W 23#		P 5.4#	I 36.315 Amperes	
4.15	5.375	0.772	4.59	0.0965	0.859
	W 21#		P 4.5#	I 34.165 Amperes	
4.01	5.271	0.76	4.41	0.0922	0.879
	W 18#		P 4.45#	I 27.8 Amperes	
3.24	4.085	0.792	3.44	0.0689	0.821
	W 16#		P 3.5#	I 26.65 Amperes	
3.11	3.906	0.797	3.32	0.0628	0.81
	W 12#		P 3#	I 20.58 Amperes	
2.165	2.886	0.75	2.3	0.0571	0.752

Circle Diagram Results.

R = 0.238 Ohm, R' = 0.119, R" = 0.144 Ohm, core loss (phase) = 138 Watts

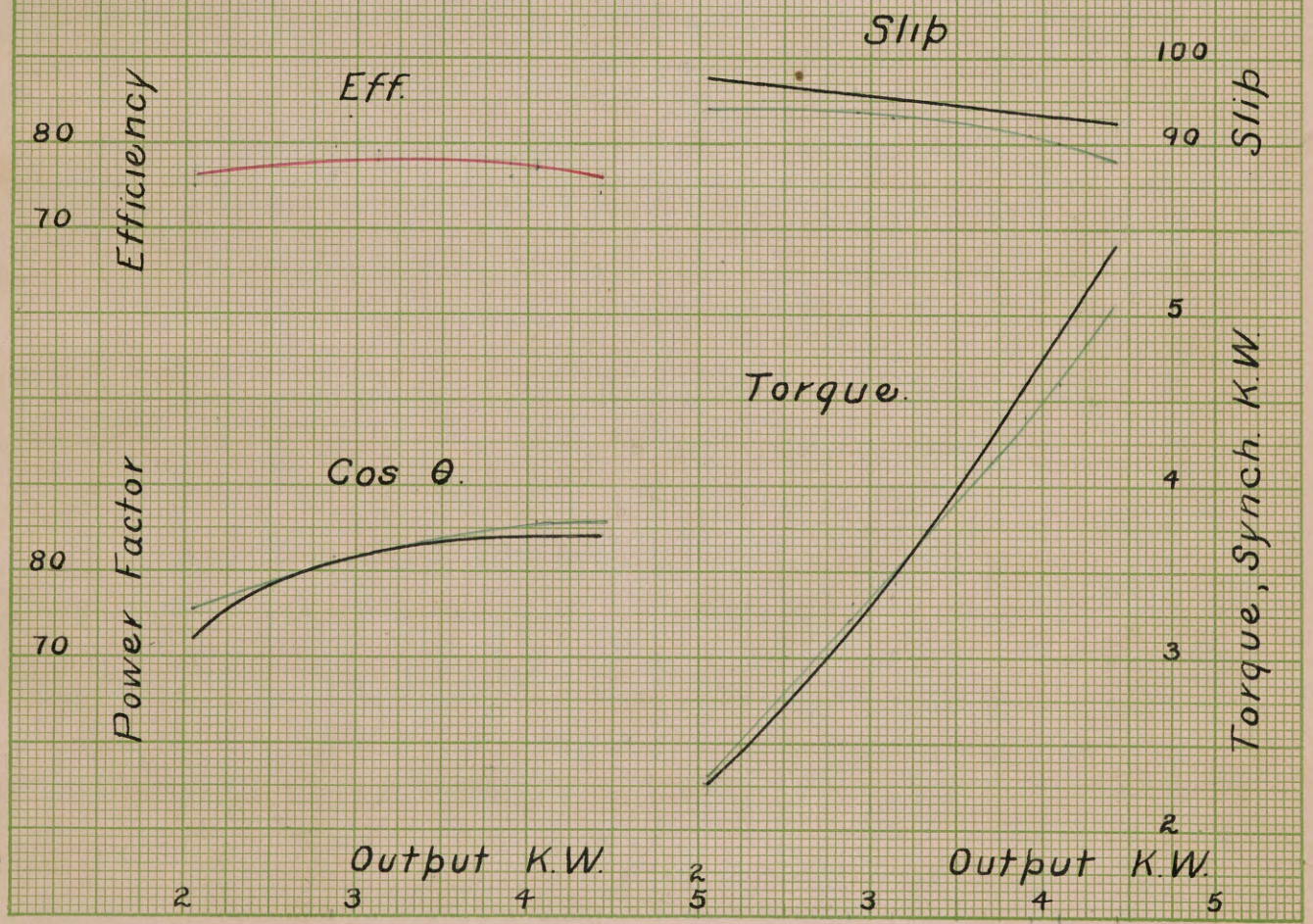
W 25# , P 5.5#	LOADS	W 23#, P 5.4#
5790 Watts	Input	5280 Watts
4813 Watts	Delivered to Rotor	4406 Watts
375 Watts	Electrical Power	305 Watts
4438 Watts	Mechanical Power	4101 Watts
0.765	Efficiency	0.776
0.078	Slip	0.0692
5.41 Synch. K.W.	Torque	4.88 Synch K. W.
0.841	Cos θ	0.841

W 21# , P 4.5#	LOADS	W 18# , P 4.45#
5010 Watts	Input	3970 Watts
4179 Watts	Delivered to Rotor	3280 Watts
265 Watts	Electrical Power	155 Watts
3914 Watts	Mechanical Power	3125 Watts
0.781	Efficiency	0.787
00635	Slip	0.0473
4.59 Synch. K. W.	Torque	3.36 Synch. K.W
0.846	Cos θ	0.82

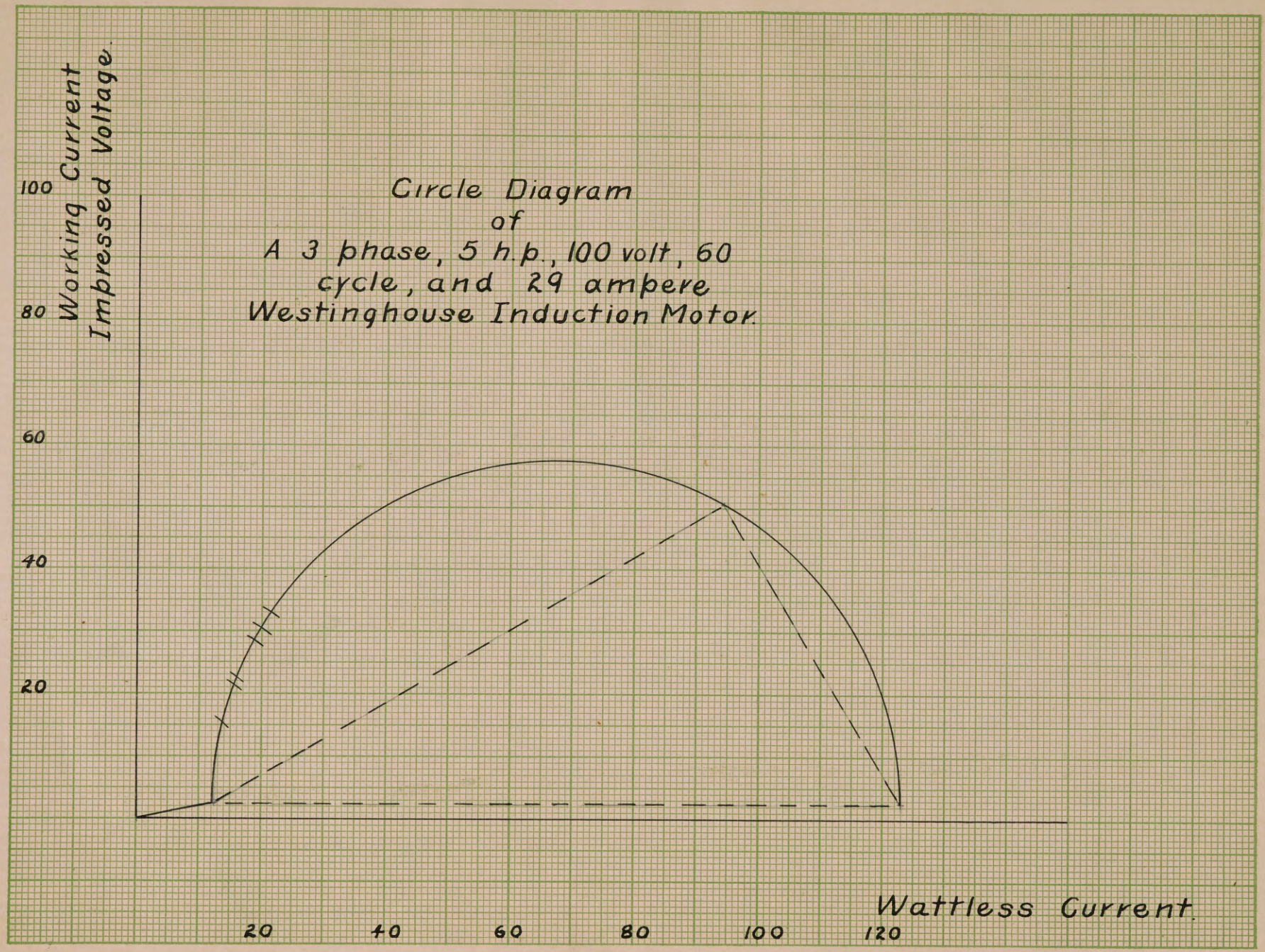
W 16#, P 3.5#	LOADS	W 12#, P 3#
3770 Watts	Input	2685 Watts
3000 Watts	Delivered to Rotor	2120 Watts
137 Watts	Electrical Power	61.5 Watts
2863 Watts	Mechanical Power	2058.5 Watts
0.761	Efficiency	0.766
0.0457	Slip	0.029
3.22 Synch K. W.	Torque	2.25 Synch K. W
0.815	Cos θ	0.72

PERFORMANCE CURVES
of
A 3 phase, 5 h.p., 100 volt, 60 cycle, and 29 ampere Westinghouse Induction Motor.

black curves, circle.
green " , brake.
red curve, brake and circle.



No. 792. KOLESCH & CO., NEW YORK.



Conclusions.

The performance curves show that at the rated full load of the motor the performance obtained by actually loading the motor compares closely with that performance predicted for the motor by the circle diagram of the motor. Above and below the rated full load of the motor the performances did not agree as well as at the rated full load, this is exactly the desirable feature of the motor's performance for no one wishes to run a machine inefficiently, that is use a large machine to carry a load not up to the rated full load with the machine running at a low efficiency. It is at times wise to sacrifice efficiency to carry overload for a short period of time but it is not economical to run an under loaded machine at a low efficiency.

Errors.

The only part of the motor's performance obtained from actually loading the motor which did not agree closely with the performance predicted by the circle diagram of the motor was the rotor slip. A thorough study as to the cause of this error revealed the fact that the method of taking the rotor speed was not accurate enough to give the desired results. After coming to this conclusion I entered a correction factor into the calculations for the motor efficiency and the synchronous torque. The changes thus obtained in the data did not change the performance curves. This conclusively proves that the speed counter was the source of the error in the slip calculation.

Considered as a whole the performance of the motor was extremely good, and at the rated full load the motor's performance was excellent.