

THE INDUCTION MOTOR
WITH ROTOR AND STATOR PARALLEL

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INTRODUCTION

Approximately, 95% of all electrical energy generated in the United States is produced as alternating current, and most of this energy is used in this form. All cities where the Edison system is still in use, are either replacing their distribution systems with A. C. networks entirely, or as the demand for energy increases are turning towards A. C. distribution. Therefore, A. C. motors are generally used in preference to D. C. motors in that they are less expensive, are generally better suited for power purposes, and to power distribution systems.

Alternating current motors are usually of the poly-phase induction type, because of their simplicity and ability to withstand severe operating conditions. It is therefore evident that any improvement in design of this type of motor would be met enthusiastically, both by the consuming public and by the manufacturers.

E. M. B.
W. H. B.

GENERAL THEORY

Usually, wound rotor induction motors are operated with the rotor circuit short-circuited; however, this is not necessary since the motor can be run by receiving power thru the rotor circuit and having the stator circuit short-circuited. There are three sources of energy to a wound rotor induction motor, namely the rotor, the stator, and the shaft. As a motor, energy is received thru either or both the rotor and stator, and energy is delivered by the shaft. As a generator, energy is received from the shaft, and delivered by either or both the rotor and stator.

The conditions for operating the motor by receiving energy thru both the rotor and the stator are that the directions of rotation of the two fields produced are such that the torque caused by the rotor and stator add. It is obvious that the two fields rotate in opposite directions. Since this is the case, the relative speed of the two fields with respect to the shaft is the difference in the speed of the fields, and it might be expected that the machine would run at this low speed. But this is not the case since the rotor and stator act independently of each other.

In starting an induction motor with the rotor and stator paralleled, it is important that the phase rotation of the rotor and stator is correct in order that the two torques will add. Figure 1 is a diagram that can be used in explaining the direction of phase rotation. With switch S_1 open and switch S_2 closed, the motor can be run by exciting the stator from a bank of transformers connected in Y, and the rotor is short-circuited thru the alternator which can be driven by a D. C. motor. The phase rotation of the stator voltage is assumed to be in the

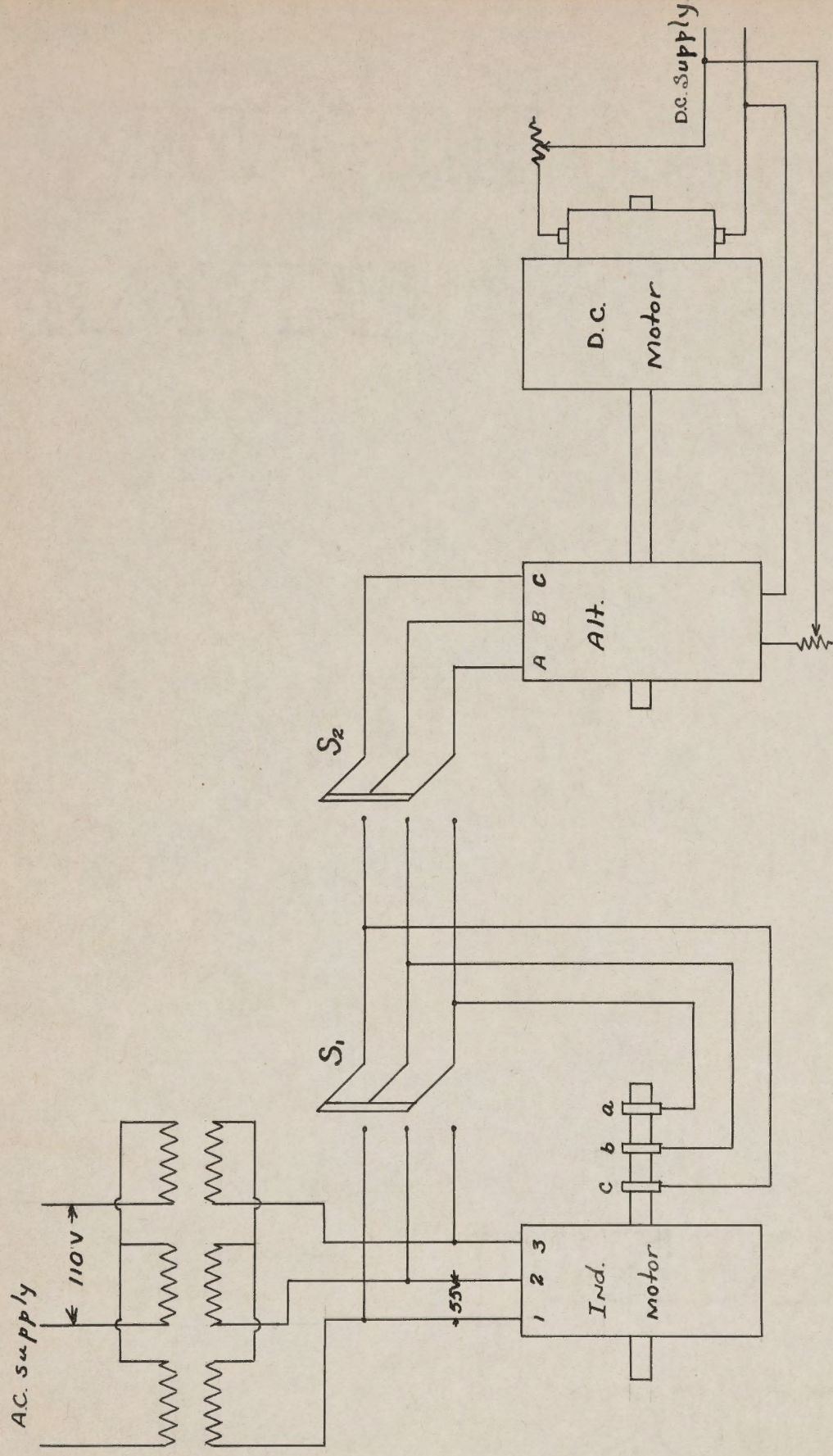


Fig. 1. Diagram of Connections.

order 1-2-3. The low frequency induced voltage of the rotor circuit caused by the revolving field of the stator will be in the order a-b-c, and since the rotor is short-circuited thru the alternator, the phase rotation with respect to the alternator will be A-B-C. Now if the A. C. supply to the stator be disconnected, the stator will be directly short-circuited thru the transformers. The motor can be driven by exciting the rotor with energy from the alternator. In order that the phase rotation of the rotor field will be opposite in direction to the phase rotation of the stator field, the order of the phase rotation in the alternator must be C-B-A, and the rotor circuit's phase rotation will be c-b-a. Voltage induced in the stator by the revolving field of the rotor will be in the order 3-2-1. If the rotor and stator are both excited at the same time as explained above, the voltage induced in the rotor by the stator field will be in the order A-B-C, and the voltage induced in the stator by the rotor field will be in the order 3-2-1. These low frequency voltages cause circulating currents to flow thru the secondary of the transformers in the stator circuit, and thru the alternator of the rotor circuit. The frequency of the rotor voltage is varied by changing the speed of the D. C. motor, and the magnitude of the voltage is controlled by a rheostat in the D. C. field. With a synchroscope across the switch S_1 , and by adjusting the frequency and voltage of the alternator properly, the alternator is synchronized with the stator supply. The switch S_2 can be opened, and the alternator stopped.

The rotor and stator are now supplied from one source, namely, the transformers. The rotor and stator are connected in parallel with this source. The low frequency circulating currents in the rotor now circulate thru the transformers and the stator,

and the circulating currents in the stator go thru the rotor and the transformers. The rotor circulating current in the stator circuit flows in the same direction as the stator supply current, but flows in the opposite direction to the stator circulating current; however, the low frequency circulating currents are so small compared to the supply current that they have very little effect on the operation of the machine (assuming a 1-1 ratio of turns in the rotor and the stator).

The conditions as just described for an induction motor with the rotor and stator parallel are just the reverse in an induction generator with the rotor and stator parallel.

It is noted that after the proper phase sequence of the rotor and stator has been determined by the method outlined above, the machine, as a motor, may be started by simply closing the supply switch and thus placing the rotor and stator across the line as a parallel circuit.

LABRATORY PROCEDURE

The machine on which tests were made was a Westinghouse wound rotor induction motor, rated 5 k.v.a., 60 cycles, 3 phase, 110-220 volts, 26-13 amperes, 1200 r.p.m. The induction machine was connected by a shaft to a Wood D.C. generator, rated 115 volts, 38 amperes, 650-1950 r.p.m. Because of the low rating of the D.C. machine the supply voltage to the induction machine was stepped down to 55 volts in order that the torque curve could be shown to the pull-out torque point when the rotor and stator were paralleled. This low voltage causes low torque and efficiency curves that are not representative of the machine, but since the purpose of the test is to compare the operation of the machine with the rotor and stator paralleled

to the operation with the rotor short-circuited, the low voltage will not materially effect the results.

Phase relations of the motor were tested, and the machine was started with the rotor and stator paralleled as before explained.

Run 1: The effeciency of the induction motor with the rotor and stator parallel was found by loading the motor with a dynamometer. The power input, line current and voltage, rotor current and voltage, speed, and the power output were measured. The power output was calculated by the formula,

$$\text{K.W.} = 0.746 \times \frac{2\pi n r F}{33,000} \text{ output.}$$

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}$$

This run is repeated for the motor with the rotor short-circuited.

The results of this test are shown on curve sheet #1. It is noticed that the efficiency of the motor with the rotor shrot-circuited reaches a maximum at an output equal to about half the output corresponding to the maximum point of the efficiency curve for the motor with the rotor and stator paralleled. This indicates that the rated output of the motor is probably doubled by paralleling the rotor and stator.

Run 2: D.C. motor and efficiency test. The D.C. motor was loaded with the dynamometer, and readings were taken of input, weight on dynamometer scale, and speed. The efficiency was found for constant speeds since the efficiency varies with the speed. The speed was kept constant by adjusting the field current. The efficiency was calculated and the results are shown on sheet #2.

Run 3: Induction generator test. The induction machine with the rotor and stator parallel was driven by the D.C. motor at speeds varying from synchronous speed (1200) to about 1350 r.p.m. At the same time, the machine was run again as a motor driving the D. C. machine as a generator. Readings were taken of speed, A.C. power, A.C. current and voltage, power factor, rotor current, D. C. current and voltage, and D.C. field current and voltage. The D.C. machine was connected so that the armature and field were separately excited from different M.G. sets.

This run was repeated for the machine with the rotor short-circuited.

The generator efficiency curves could be calculated from this data by knowing the D.C. motor efficiency from run #2. The formula would be,

$$\text{Eff. (generator)} = \frac{\text{watts output}}{E_f I_f + E_a I_a \times \text{D.C. motor eff.}}$$

These calculations are plotted on sheet #3. These curves show that the generator efficiency of the machine with the rotor and stator parallel reaches a maximum at an output of about twice the output corresponding to the point of maximum efficiency for the machine with the rotor short-circuited. Other characteristics of the machine from this run are shown on curve sheet #4.

From runs 1 and 3 the speed-torque curves of sheet #5 were calculated. The generator torque was calculated by the formula,

$$\text{Torque} = \frac{K.W. \text{ output} \times 33,000}{2 \ n \times 0.746} \text{ ft. lb.}$$

These curves indicate that the generator capacity was increased by paralleling the rotor and stator, and that

the pull-out torque of the machine was increased by paralleling.

There is no doubt but that the pull-out torque of the motor when the rotor and stator are paralleled would be nearly doubled if the machine was designed to have a rotor and stator paralleled. The machine on which the test was made was unsuitable in that the ratio of turns of the rotor and stator was about 1 to 5. This made the rotor circuit a low impedance circuit, and for this reason most of the line current went thru the rotor circuit. This unbalance of currents made it impossible to load the stator to full load without overloading the rotor. For this reason the pull-out torque was not as high as it would have been with a proper design.

ADVANTAGES AND DISADVANTAGES

The advantages of paralleling the rotor and stator are more numerous than the disadvantages. The advantages may be listed as follows:

1. The rating of the machine is increased very much, and with a proper design, the rated output might be doubled.
2. The machine can be operated with large loads at high efficiency. In the case of a variable load, a special switching device might be designed and placed in the rotor circuit between the slip rings and the line to act as follows: when the load is high, the machine will operate with the rotor and stator parallel, and the operation will be on the curve that gives high efficiencies for high loads; when the load drops to a certain point, a relay will operate the switching mechanism which short-circuits the rotor circuit, and the operation at this load will shift to the curves giving high efficiencies at low loads. (See curve sheet #3).

There was only one noticeable disadvantage in the parallel operation of the machine. This was that the line current to the machine with the rotor and stator paralleled was very much higher than the line current to the machine with the rotor short-circuited. This comparison was made for the same output. This is a serious disadvantage, but even it does not have weight when compared to the advantages.

It would be possible when operating an induction motor of this type with the rotor and stator paralleled, to connect the rotor to the high voltage line thru auto-transformers. This would give better operation in that the rotor voltage would be reduced, and also the transformers would serve to by-pass the low frequency currents that ordinarily circulate thru the supply transformers.

OSCILLOGRAMS

All oscillograms included in this report show conditions that may be expected in induction motor operation with the rotor and stator paralleled.

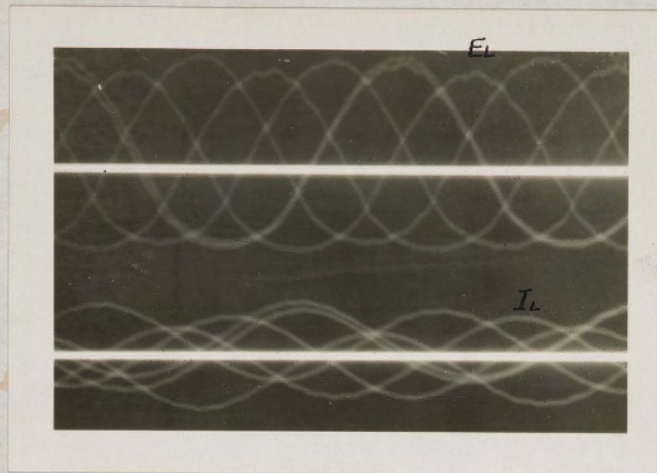
As we have shown, the low frequency currents induced in the rotor and stator of the machine must complete their circuit by flowing thru the secondary of the supply transformers, and thru the alternate motor circuit. With this condition, we can anticipate some rather irregular wave shapes in both the current and voltage vectors, in that both the transformers and the motor will operate at a point on a saturation curve higher than would be normally expected. It is understood that this point will swing back and forth with the low frequency currents. Considering this theory correct, we might expect the voltage

wave to show more of a round top curve during part of the cycle due to high iron saturation. Oscillogram #4 shows this result very clearly, and also the shifting of the voltage axis. It is noted, however, that the rounded top curves seem to adhere to the negative half of the cycle at all times rather than following the low frequency currents as does the no-load currents.

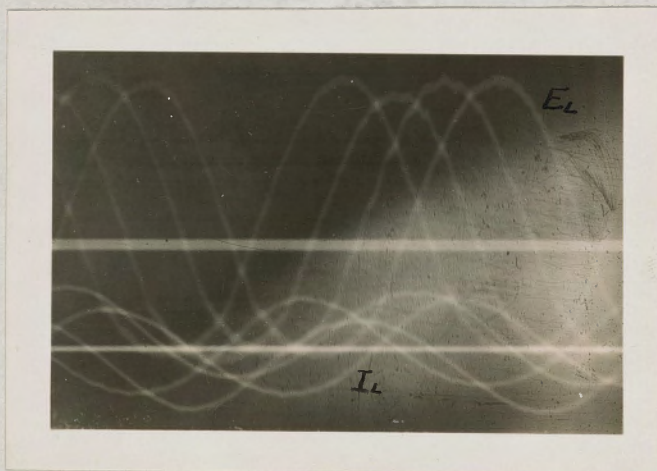
Another peculiarity noted is shown in oscillogram #5, which shows the stator current with the machine acting as a motor. The effect of the low frequency circulating current is clearly shown by a triple exposure, and magnified by the fact that the stator load current is relatively low as compared with that of the rotor. It is also noticed that the ripples in the wave formed due to slots do not follow the wave crest as would be normally expected, but rather fall in that part of the curve that denotes a change of amplitude. This effect was probably due to a strong cross magnetizing flux in the circuit.

Except for the above mentioned singularities, the oscillograms are much the same as those obtained with the ordinary type of induction motors.

OSCILLOGRAMS

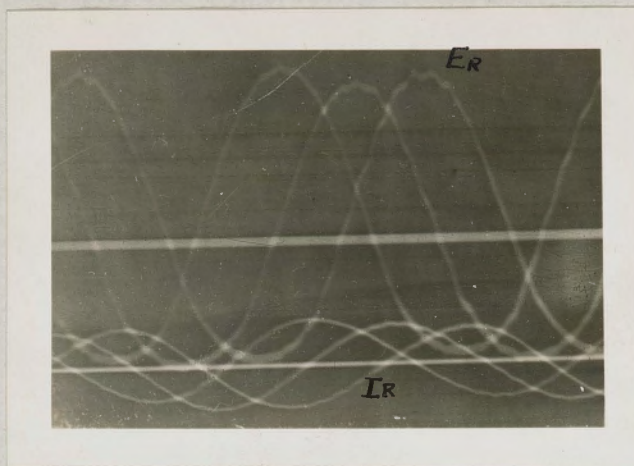


Picture #1. Line current and voltage to the machine with rotor and stator paralleled. Machine acting as a motor.

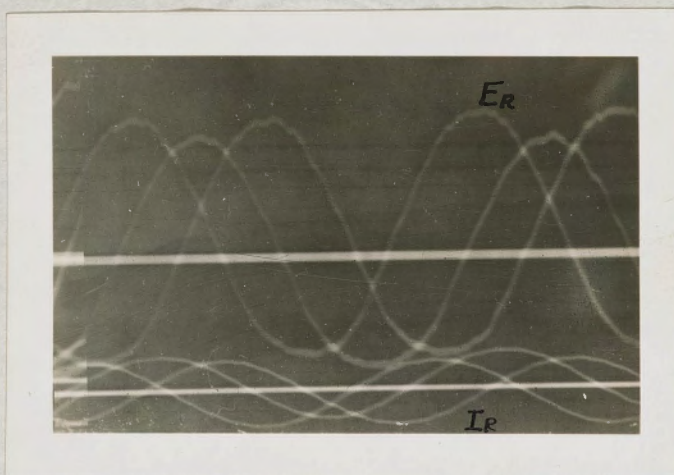


Picture #2. Line current and voltage to the machine with rotor and stator paralleled. Machine acting as a generator.

OSCILLOGRAMS

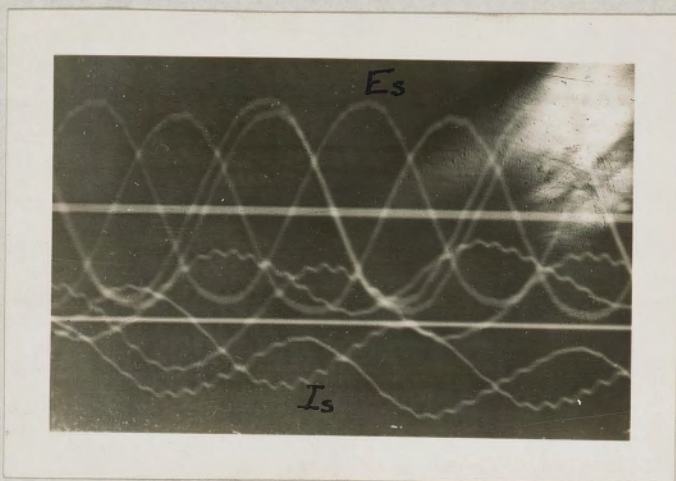


Picture #3. Rotor current and voltage to the machine with rotor and stator paralleled. Machine acting as a motor

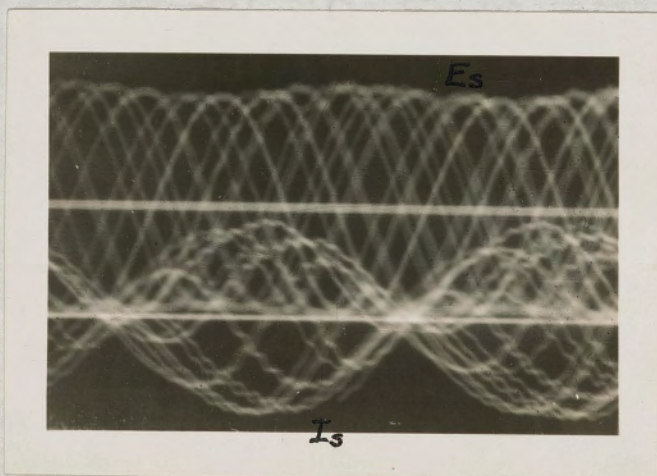


Picture #4. Rotor current and voltage to the machine with rotor and stator paralleled. Machine acting as a generator.

OSCILLOGRAMS



Picture #5. Stator current and voltage to the machine with rotor and stator paralleled. Machine acting as a motor.



Picture #6. Stator current and voltage to the machine with rotor and stator paralleled. Machine acting as a generator.

RECORDED DATA AND CALCULATIONS

Run #1. Speed torque curve data. Motor loaded with dynamometer. Rotor and Stator parallel.

Scale Weight	Line Volts	Line Amps.	Power Input	Power Factor	Speed	Horse Power	Power Output	Eff.	Torque
1# 4 oz.	50	22.5	900	61 lag.	1133	0.675	503	56%	3.12
1 10 "	50	23.8	1050	66 "	1100	0.85	633	57½%	4.07
2 3 "	48	27.5	1300	74 "	1065	1.10	820	63.2%	5.45
3 0 "	46	35.0	1700	80 "	984	1.40	1040	61.0%	7.50
3 4 "	45	37.5	1800	80 "	967	1.49	1110	61.5%	8.12

Speed torque curve data. Loaded with dynamometer.
Rotor short-circuited.

Scale Weight	Line Volts	Line Amps.	Power Input	Power Factor	Speed	Horse Power	Power Output	Eff.	Torque
0# 7 oz.	53.8	7.5	500	74 lag.	1150	0.239	178	35.6%	1.09
0 11 "	53	8.5	600	77 "	1134	0.37	276	46.0%	1.71
1 9 "	51.5	16.	1000	82 "	1100	0.817	610	61.0%	3.9
2 2 "	50	17.	1300	83 "	1075	1.08	805	62.0%	5.3
2 10 "	48.5	21.5	1500	83 "	1025	1.28	842	56.0%	6.56
2 14 "	47.	25.	1700	84 "	958	1.31	977	57.5%	7.22

Run #2. D. C. Motor efficiency test.

Armature Voltage	Armature Current	Speed	Load	E_a	I_a	Horse- power	Load Watts.	Eff.
115	4.6	1100	0	527	0	0	0	0
113	6.4	1100	0.783	723	0.41	305	42%	
117	9.8	1100	1.405	1140	0.735	548	47.8	
116	11.5	1116	1.875	1350	0.965	720	53.5	
115	14.4	1116	2.437	1650	1.255	937	57.0	
115	18.3	1116	3.625	2100	1.87	1395	66.5	
116	21.2	1116	4.783	2460	2.47	1840	74.8	
116	29.2	1116	6.25	3390	3.22	2400	71.0	
116	27.6	1235	5.187	3200	2.38	1775	55.4	
116	22.8	1235	4.09	2640	1.88	1400	53.0	
116	19.0	1235	3.31	2210	1.52	1130	51.0	
116	16.5	1235	2.75	1915	1.26	940	48.0	
116	13.8	1235	2.12	1600	0.975	727	45.5	
116	11.8	1235	1.69	1370	0.775	577	42.0	
116	8.0	1235	0.81	928	0.372	277	29.8	
116	6.8	1235	0.56	788	0.257	192	24.4	

Run #3-A. Induction machine run as a motor and as a generator with rotor and stator parallel. Loaded with D. C. machine.

Power Factor	Line Volts	Line Amps.	Input Watts	Rotor Amps.	D. C. Arm. Amps.	D. C. Field Volts	D. C. Field Amps.	D. C. Field Volts	Speed
69 lag.	48.5	25.6	1200	20.5	4.5	116	0.9	87	1092
59 "	50.0	22.8	912	17.0	2.0	115	0.8	87	1132
77 "	47.0	29.6	1440	25.0	5.5	116	0.9	86	1050
80 "	46.0	34.0	1680	29.0	7.0	116	1.0	86	1000
81 "	45.0	38.4	1825	32.5	7.5	116	1.08	86.5	950
84 "	44.0	42.5	1900	35.0	8.0,	116	1.1	86.0	892
57 Lead	55.5	30.8	1280	25.6	20.5	112	0.55	86.0	1275
61 "	56.0	34.4	1620	30.8	26.0	111	0.9	86.0	1300
69 "	56.5	40.0	2020	36.2	32.5	111	0.49	86.0	1315
69 "	57.0	43.0	3240	39.7	37.0	111	0.45	86.0	1342
70 "	57.0	45.0	3400	42.2	40.0	111	0.45	86.0	1350

Run #3-B. Induction machine run as a motor and as a generator with rotor short-circuited. Loaded with D. C. machine.

Power Factor	Line Amps.	Line Volts	Input Watts	Rotor Amps.	D. C. Arm. Amps.	D. C. Volts	D. C. Field Amps.	D. C. Field Volts	Speed
69 lag.	8.8	53.0	560	6	0	113	0.75	105	1150
85 "	16.2	51.0	1200	16.6	4.25	118	0.9	104	1092
85 "	23.5	48.0	1630	26.5	6.5	118	0.95	104	1015
80 "	28.0	46.5	1800	33.0	6.5	118	1.05	104	950
80 "	30.0	46.0	1840	36.3	6.5	117	1.1	87	883
65 lead	10.0	57.0	647	9.0	11.5	111	0.6	104	1215
82 "	13.2	58.0	976	13.5	15.5	111	0.58	104	1250
82 "	16.0	59.0	1293	18.0	19.5	111	0.55	105	1265
82 "	19.5	60.0	1600	23.0	24.0	110	0.55	105	1285
80 "	23.4	60.5	1975	30.3	29.5	110	0.5	89	1315
79 "	28.0	60.5	2300	24.3	36.0	111	0.45	88	1415
80 "	29.2	61.0	2400	39.5	38.0	111	0.45	88	1415
78 "	7.43	56.0	400	4.0	7.5	111	0.6	104	1200

Slip curve data.

Rotor short-circuited			Rotor and Stator paralleled		
Line Power	Speed	%Slip	Line Power	Speed	%Slip
560	1150	3.37	1200	1092	8.4
1200	1092	8.23	912	1132	5.05
1630	1015	14.7	1440	1056	11.8
1800	950	20.1	1680	1000	16.0
1840	883	25.8	1825	950	20.2
647	1225	2.95	1900	892	25.1
976	1250	5.05	1280	1275	7.15
1293	1265	6.3	1620	1300	9.25
1600	1285	8.0	2020	1315	10.5
1975	1315	10.5	3240	1342	21.2
2400	1415	19.0	3400	1350	21.9

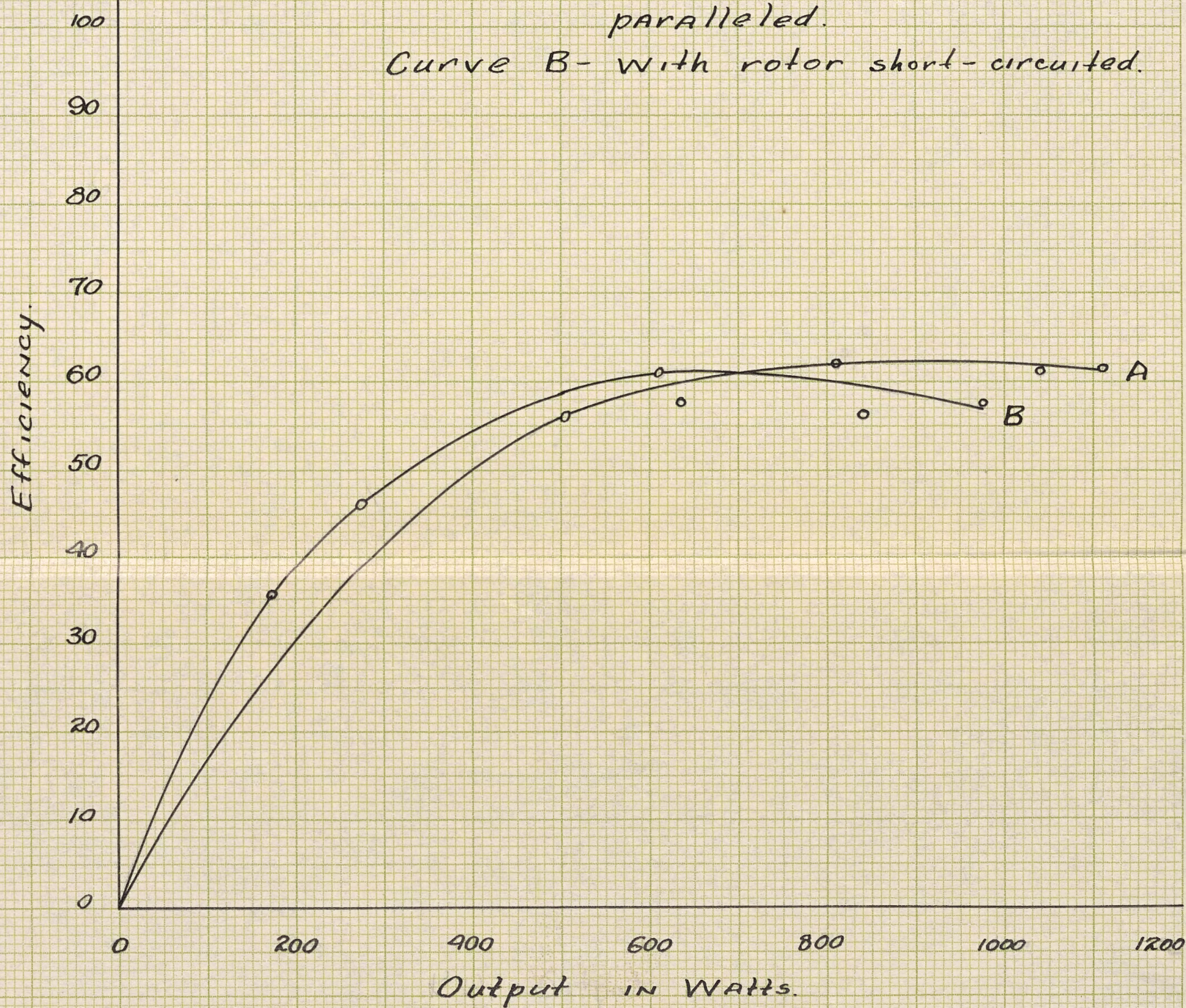
Synchronous speed = 1190 r.p.m.

Sheet #1

Efficiency of the induction
machine as a motor.

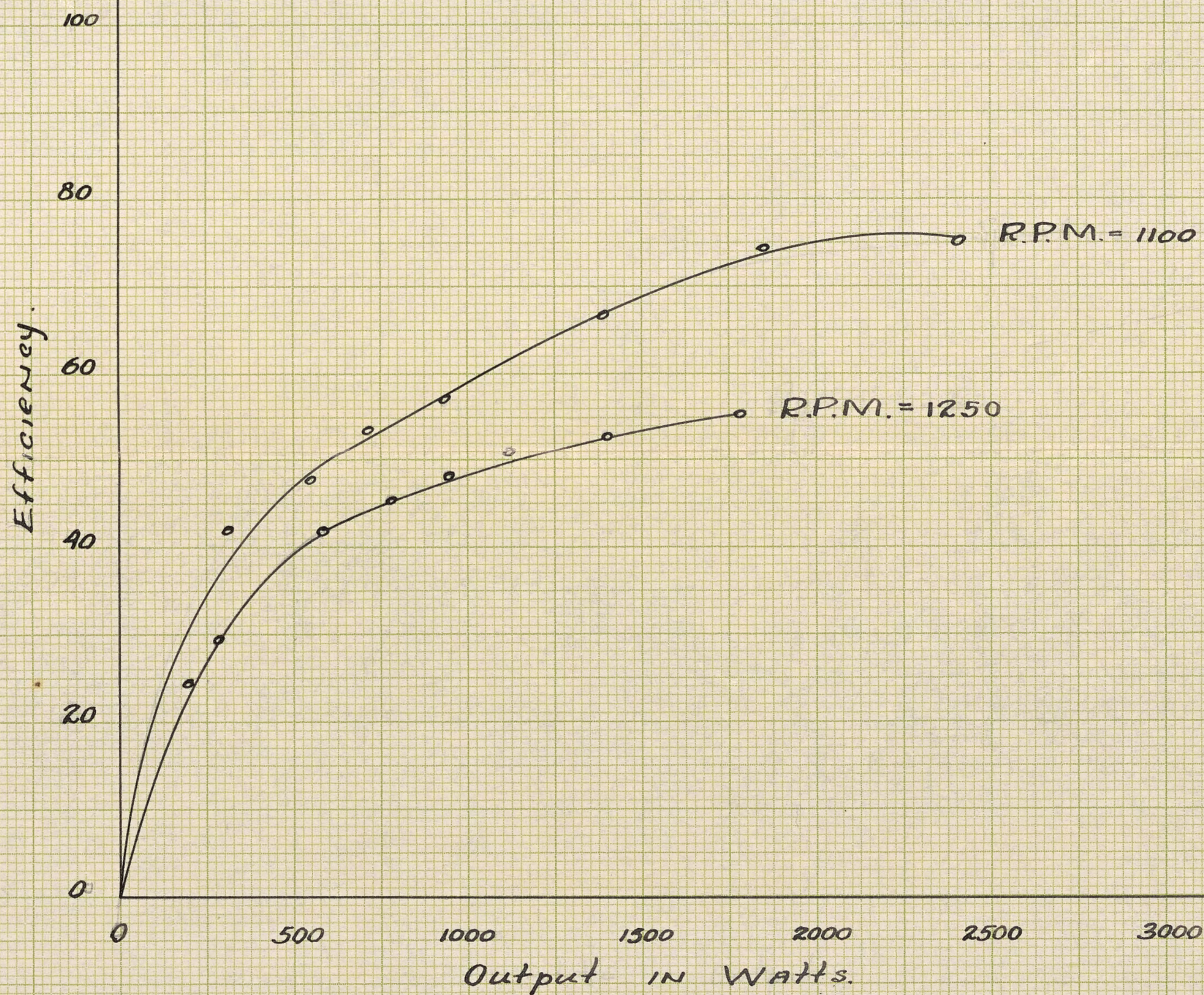
Curve A - With rotor and stator
paralleled.

Curve B - With rotor short-circuited.



Sheet #2.

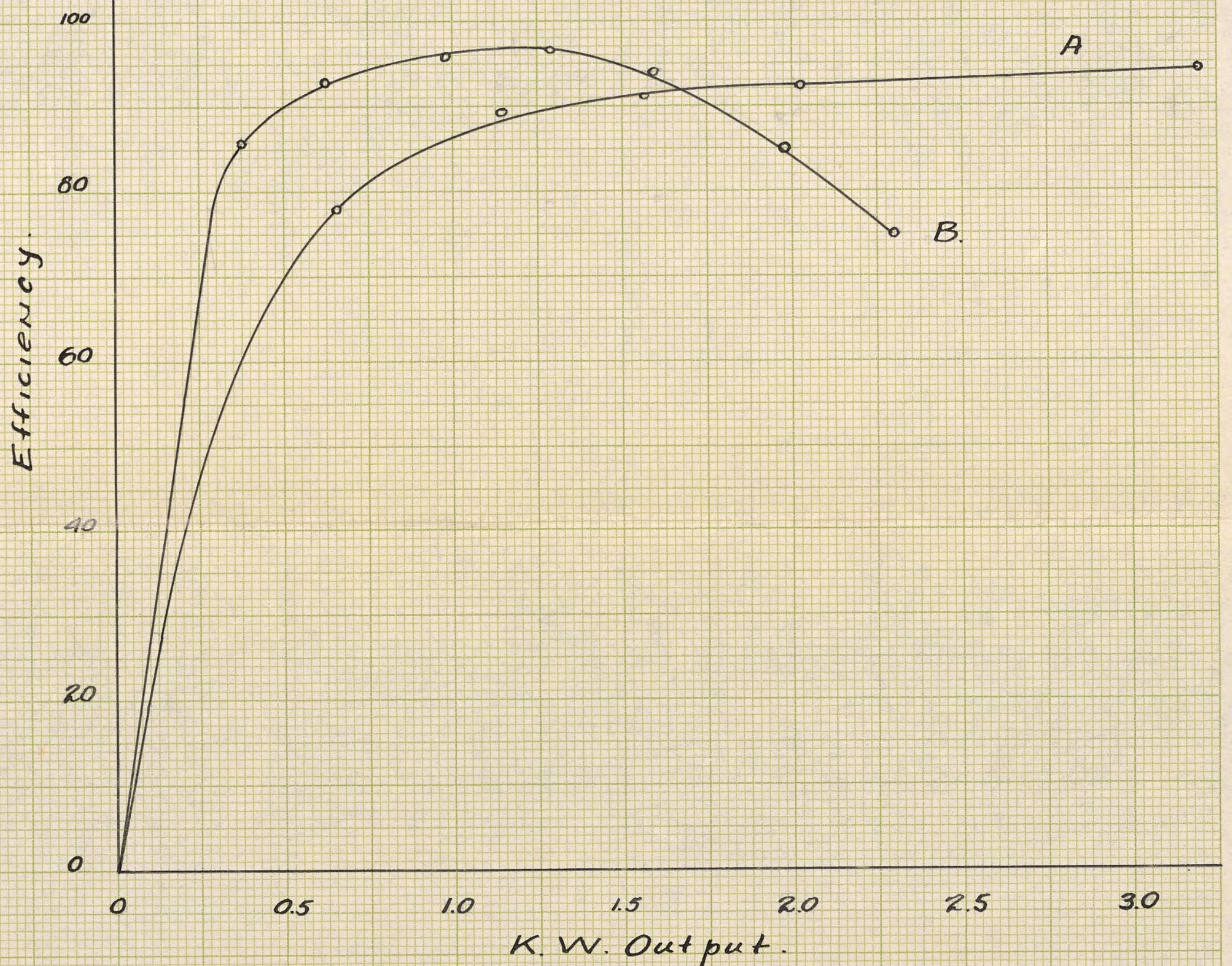
Efficiency curves of the
Wood D.C. Motor.



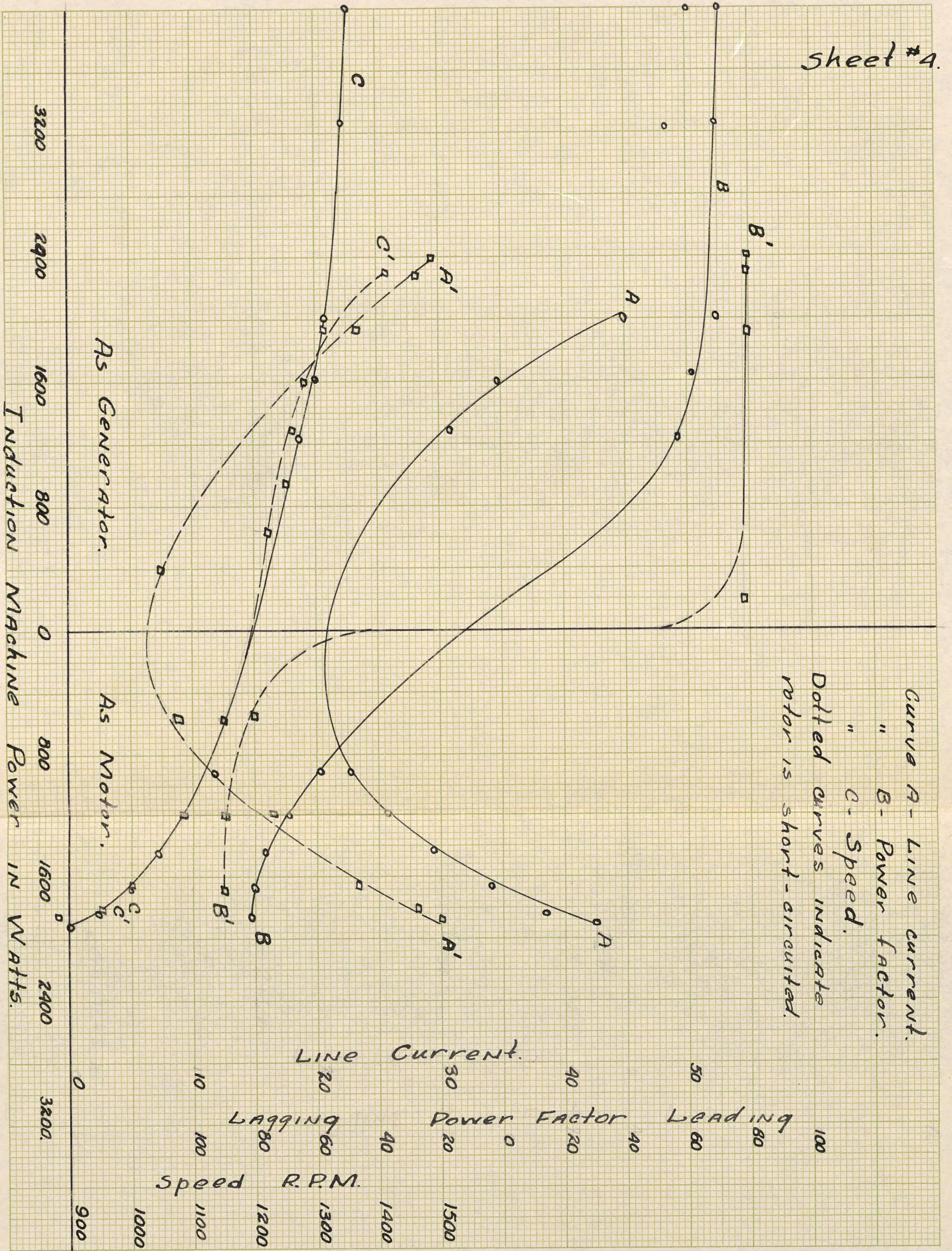
Sheet #3.

Efficiency of the induction
machine as a generator.

Curve A - Rotor and stator paralleled.
Curve B - Rotor short circuited.



Sheet #4.



Sheet #5.

Speed Torque Curves of Induction Machine.

Curve A - Rotor and stator paralleled.

Curve B - Rotor short circuited.

Generator.

Motor.

20

16

12

8

4

0

4

8

12

Torque - Ft. lbs.

1400

1200

1000

800

600

400

200

0

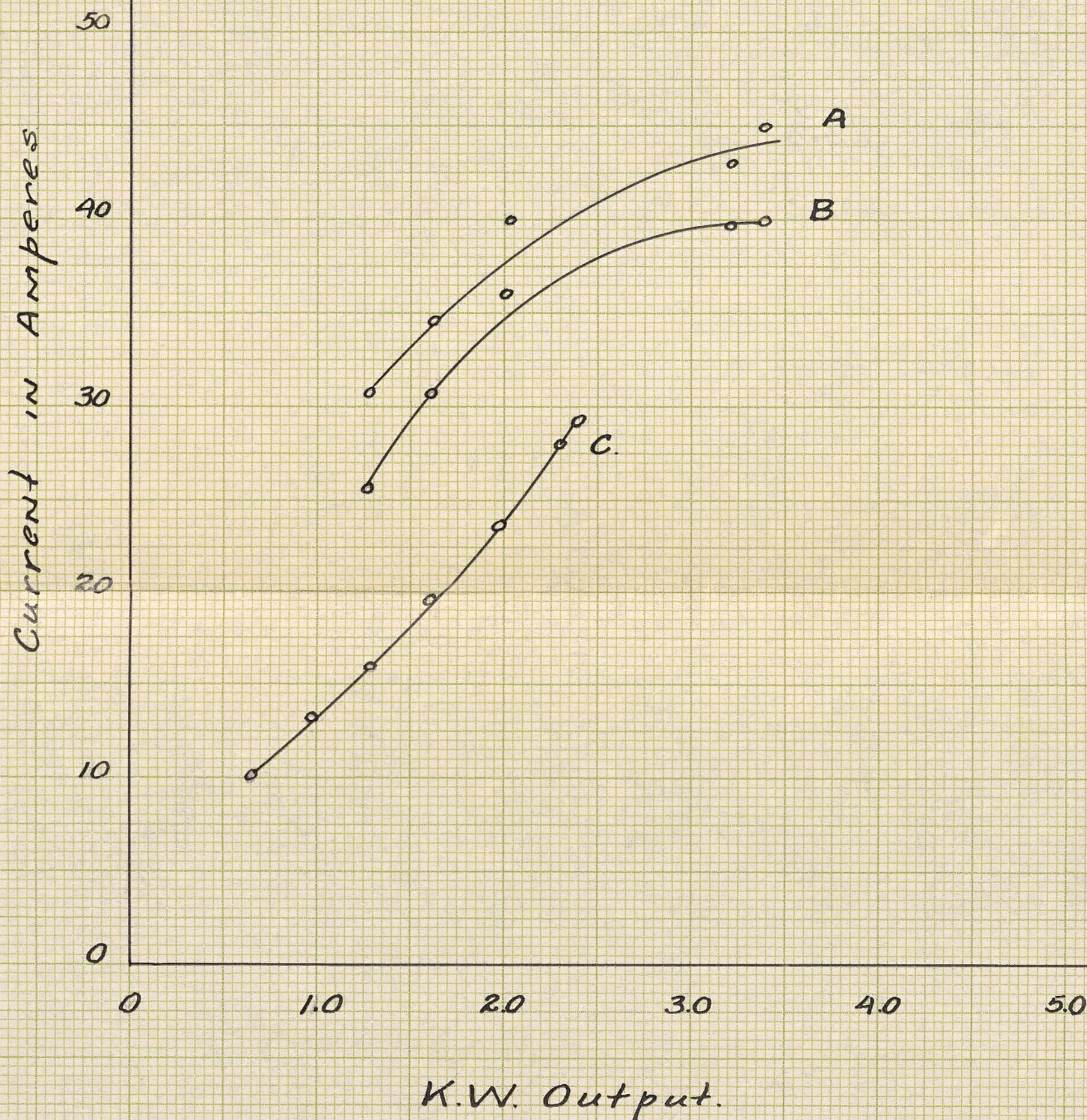
Speed - R.P.M.

A
B

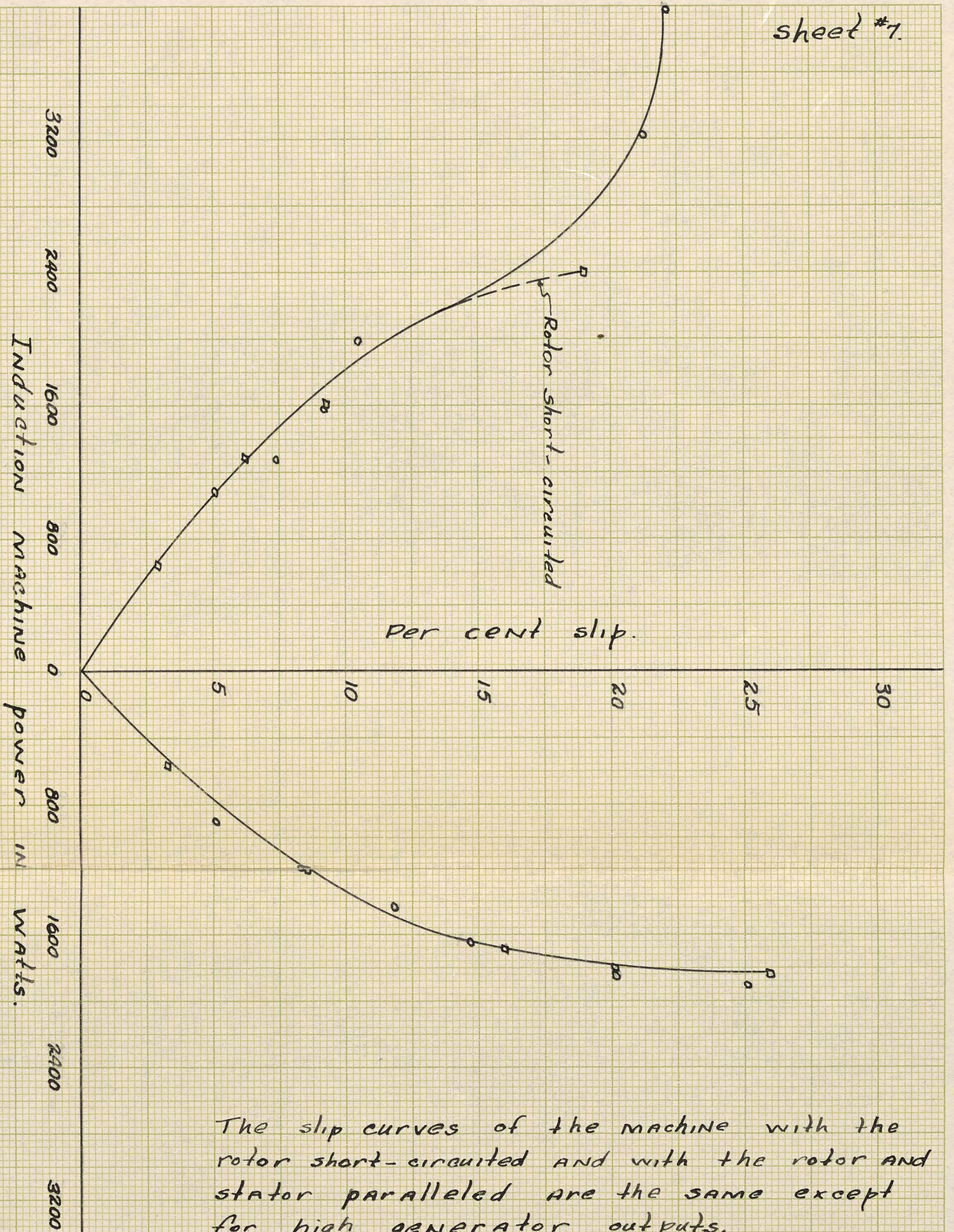
Sheet #6

Generator currents of the induction machine.

Curve A - Line current } Rotor and
Curve B - Rotor " } stator paralleled.
Curve C - Line current with
rotor short-circuited.



sheet #7.



The slip curves of the machine with the rotor short-circuited AND with the rotor and stator paralleled are the same except for high generator outputs.

APPROVAL

The foregoing thesis is hereby approved as a credit-able 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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TITLE

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