A TENNESSEE ALTERNATOR.

Thesis
by

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A TENNESSEE ALTERNATOR.

The Dynamo under discussion was built in the shops of the University of Tennessee from an original design and is used in the Physical Laboratory for experimental pupposes. It is known as the R.H. Alternator and is driven by a direct connected Westinghouse motor. The following data will describe the machine.

Output in kilowatts	3
Amperes	10
Volts (no load)	500
Volts (full load)	300
Revolutions per minute	1000
Frequency	33
Number of poles	4
~~Diameter~~ Radius of field pitch circle	3 1/2 in.
Length of magnet cores	4 in.
Section of magnet cores	
Length	2 1/2 in.
Width	2 in.
Pole faces	
Length	6 in.
Width	3 in.
Turns on each core	1758
Exciter current (full load)	2 amperes
Resistance of fields	58.825 ohms
Armature core	
Length of core	6 in.
Number of coils	4
Length of coils	9 in.
Width of coils	4 in.
Connection of armature to motor	Direct.

The tests made upon this machine which will be described in this paper are the following.

(1) To find the number of turns of wire on the armature.

(2) To explore the magnetic leakage.

(3) To determine the Curve of Magnetization.

(4) A study of the curves of Current and E.M.F. with various loads.

(5) External Characteristic

During the test the field coils were connected two coils in series and two series in parallel and excited by a current of two amperes.
Only one coil of the armature was used (known as coil A) which gave a voltage of about 140 on open circuit.

The first experiment was to find the number of turns of wire on the armature. To get this twenty turns of fine wire were wound as a test coil at an average position on one coil of the armature. With the field excited and the poles of armature and field opposite the test coil was connected in series with the armature coil and a galvanometer, first so as to help the armature coil in deflecting and then so as to oppose it. From which arrangement the number of turns may be calculated.
Two trials were made, one from the Thompson-Ryan dynamo at shop and another using the storage battery for exciting current.
Readings were both on opening and closing the circuit.
The following tables give results obtained which show the number of turns on one coil of the armature to be 180. This means the total number of turns to be about 720.

TO FIND THE NUMBER OF TURNS ON THE ARMATURE.

Trial No. 1 Exciting current .3 ampere from T.R. dynamo.

Test coil helping.

Closing circuit				Opening circuit	
Deflection	Throw	Galvanometer standing		Throw	Deflection
24	72	48	48	22.3	25.7
24.2	72.2	48	48	22.3	25.7
24.3	72.4	48.1	48.1	23	25.1

Average deflection 24.167 Average deflection 25.467

Average from both 24.817

Test coil opposing

Closing circuit				Opening circuit	
Deflection	Throw	Galvanometer standing		Throw	Deflection
19	67	48	48	26.7	21.3
19	67	48	48	26.8	21.2
19.1	67.1	48	54.2	33.7	20.5
20.2	78.2	58	58	38.7	19.3

Average def. 19.32 Average def. 20.575

Average from both 19.947

TO FIND THE NUMBER OF TURNS ON THE ARMATURE.

Trial No. 2 Exciting current .3 ampere from storage battery.

Test coil helping.

Closing circuit				Opening circuit.	
Deflection	Throw	Galvanometer standing		Throw	Deflection
25.4	80.6	55.2	38.2	13.7	24.5
25.7	80.6	55.2	38.8	13.6	25.3
24	63.6	39.6	38.5	13.8	24.7
23.7	63.5	39.8	38.7	13.8	24.9

Av. def. 24.7 Av. def. 24.85

Average from both 24.775

Test coil opposing

Closing circuit				Opening circuit	
Deflection	Throw	Galvanometer standing		Throw	Deflection
17	75	58	56	36.2	19.8
19.2	74	54.8	56.5	35	21.5
20.9	74.8	53.9	56.9	34.9	22
18.2	75.1	56.9	55	35.2	19.8

Av. def. 18.82 Av. def. 20.8

Average from both 19.81

Average N from both trials 180.

EXPERIMENT 2 MAGNETIC LEAKAGE.

The magnetic leakage was investigated by means of a ballistic galvanometer and a single turn of wire placed first at different positions on the field so as to show where strongest and then placed at a mid position on the armature so as to include all the lines of force entering the armature from the field coil just tested. The difference of deflection is proportional to the leakage

A current of .3 ampere is used first and then a current of 3 amperes. Naturally the greatest leakage occurs when the strongest current flows in the field. Deflections were read both on making and breaking the circuit.

The values obtained for leakage are low and show that the magnetic circuit is probably not saturated and also indicate an excellent mechanical construction as the clearance is very small. Following are the results tabulated.

Current .3 ampere

Test coil around bottom of pole piece (upper field).

Opening circuit				Closing circuit	
Deflection	Throw	Galvanometer standing		Throw	Deflection
8.3	29.7	38.0	39.2	46.5	7.3
8.5	30.1	38.6	39.4	46.4	7.0
8.3	29.7	38.0	38.6	46.2	7.6

Average deflection 7.83

Test coil around bottom of field coil.

8.8	48.2	39.3	38.7	30.3	8.4
8.6	48.5	39.9	38.6	30.2	8.4
8.7	48.3	39.6	38.7	30.4	8.3

Average deflection 8.54

Test coil around middle of field coil.

9.0	48.5	39.5	38.0	30.1	7.9
9.1	48.4	39.3	38.4	30.2	8.3
8.7	48.6	39.9	38.8	30.4	8.4

Average deflection 8.73

MAGNETIC LEAKAGE (continued).

Field current .3 ampere.

Test coil around top of field coil.

Opening circuit				Closing circuit	
Deflection	Throw	Galvanometer standing		Throw	Deflection
9.1	48.4	39.3	38.5	30.3	8.2
8.9	48.7	39.8	38.7	30.5	8.2
9.5	48.0	38.5	38.7	30.2	8.5

Average deflection 8.73

Test coil around armature coil.

8.1	47.6	39.5	38.2	30.9	7.3
8.2	47.5	39.3	38.8	32.2	7.7
8.3	47.5	39.3	38.8	31.0	7.5

Average deflection 7.85

The leakage coefficient for this field current = N ÷ n = 1.11

Field current 3 amperes.

Deflection	Throw	Galvanometer standing		Throw	Deflection
		Test coil around pole piece of field.			
5.8	43.9	38.1	38.2	32.7	5.5
5.7	43.9	38.2	38.7	32.8	5.9
5.1	43.8	38.7	38.1	32.4	5.7
		Average deflection 5.61			
		Test coil around bottom of field coil.			
7.5	45.1	38.6	38.6	31.1	7.5
7.3	45.1	38.8	38.6	31.2	7.4
7.8	45.1	38.3	38.5	31.3	7.2
		Average deflection 7.44			
		Test coil around middle of field coil.			
7.4	45.4	38.0	38.7	30.9	7.8
7.4	45.2	37.8	37.9	30.6	7.3
7.3	45.3	38.0	38.6	30.7	7.9
		Average deflection 7.51			
		Test coil around top of field coil.			
7.6	45.5	37.9	37.7	30.7	7.0
7.3	45.4	38.2	38.3	30.8	7.5
7.5	45.2	37.7	38.0	30.8	7.2
		Average deflection 7.33			
		Test coil around center of armature coil.			
6.4	44.7	38.3	38.3	32.0	6.3
6.2	44.6	38.4	38.2	31.9	6.3
6.3	44.6	38.3	38.2	31.9	6.3
		Average deflection 6.3			

The leakage coefficient for this field current = 1.192

A peculiarity is noticed by a study of these results namely that more lines of force pass through the armature coil than pass through the pole face just opposite. These lines of force must come from the upper part of the field through the air and into the armature core, which goes to show the large amount of iron in the armature core.

Experiment 8 To determine the Magnetization Curve.

This is a very useful curve in tracing the magnetic circuit. It was taken in the usual way, the magnetizing current being measured by an amperemeter and the pressure at the brushes by a Cardew voltmeter up to 87 volts and from there up by an Electrostatic voltmeter, the speed being held at about 1000 R.P.M. The exciting current was varied by means of a bank of lamps in series with the field. The voltmeters were calibrated by comparison with a Weston direct current voltmeter. A table follows showing the method of calibration. In the table for the magnetization curve corrected voltmeter readings are given. The dotted section at the top shows a correction on account of variation of speed. The magnetization was followed up and down and the difference shows the tendency of the iron to retain its magnetization.

Plate 1 shows this curve.

TABLE FOR CALIBRATION OF VOLTMETERS.

Taken May 8th, 1901.

Weston	Cardew		Electrostatic	
Used as standard	Reading	Error	Reading	Error
26.8	29	2.2		
30.5	33	2.5		
42.5	45.3	2.7		
51.5	55.5	4	52	.5
65	69	4	65	0
88.5	93	4.5	88.5	0
94.5	99	4.5	95	.5
97.5	102.5	5	98.5	1
99	105	6	100.5	1.5
104.5	110	5.5	105	.5

TABLE FOR MAGNETIZATION CURVE

Taken May 8th 1901.

Speed in R.P.M.	Amperes exciting current	Volts (corrected). Cardew Up	Cardew Down	Electrostatic Up	Electrostatic Down
1000	.1	2	2		
1000	.2	4	7		
1000	.3	22	28		
1000	.5	39	43		
1000	.7	55.5	62		
1000	1	72	78		
1000	1.2	87	89	87*	89
1000	1.4			99.5	107.5
1000	1.5			106	
1000	1.6			110.5	117
1000	1.7			115	
1000	1.75			121	125
1000	1.8			124	128
1000	1.85			126	
1000	1.9			126.5	
1000	1.95			128	131
1000	2			129.5	
1000	2.03			130.5	
1000	2.07			134	136
990	2.1			135	
990	2.25			140	140
990	2.3			142	
990	2.4			143	143
990	2.45			143	
980	2.48			143	
980	2.5			144	

* Up to this point the Electrostatic voltmeter did not give satisfaction.

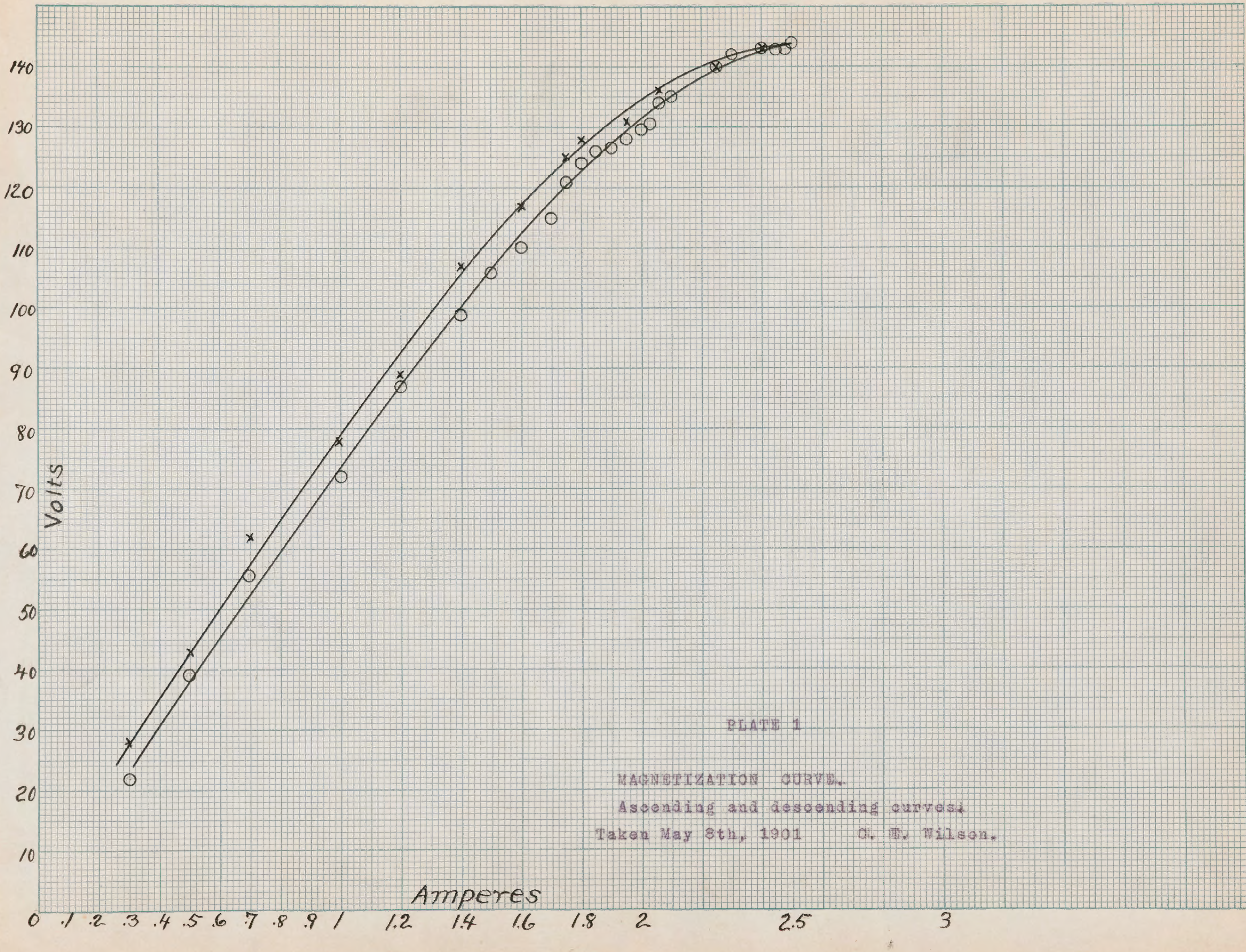


PLATE 1

MAGNETIZATION CURVE.

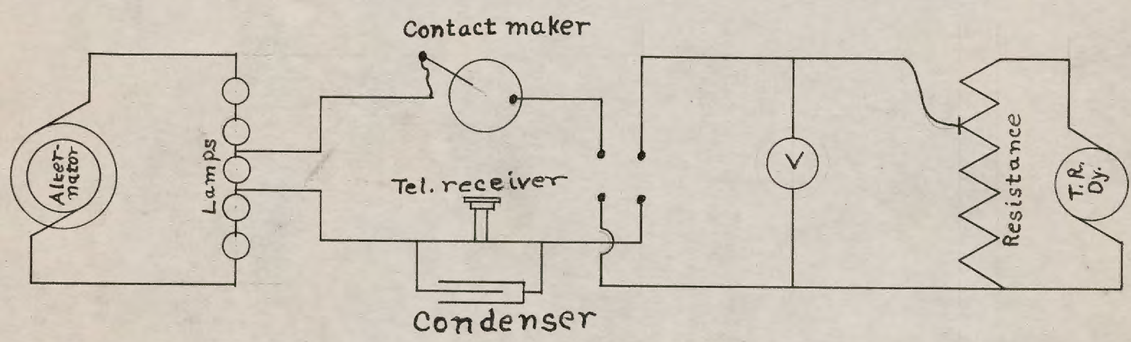
Ascending and descending curves.

Taken May 8th, 1901 C. E. Wilson.

Curves of E.M.F.

The next experiments were the determination of a series of curves of E.M.F. and current taken by means of instantaneous contact and under different conditions as to load. The study of these curves is interesting and of much importance as they show the change in instantaneous values for E.M.F. and current due to the position of the coils with reference to the poles, the difference between the real curve and the sinusoidal, the angle of lag, the distribution of magnetism over the pole faces and any irregularity that may occur in the position or winding of poles.

The method used in this determination was one devised by Mr R. D. Hershon an engineer of the Westinghouse Electric Co. and following is a diagram of the connections.



The telephone receiver is connected in circuit with the contact maker and gives a sharp click when contact is made due to the instantaneous pressure for that position, but when this pressure is exactly balanced by a continous pressure being introduced the receiver should be silent. In these experiments, pressure from the Thompson-Ryan dynamo at the shop was used as a balancing pressure for high values and the storage battery for low ones.

It was necessary to cut down the pressure from the alternator by means of five lamps in series as the continous current machine only reached 100 volts while the alternator sometimes went as high as 300 volts.

To obtain an inductive load a transformer, with secondary open, was connected in parallel with the lamps. To get the instantaneous current values a non inductive resistance was introduced in series with the transformer and the fall of pressure measured from its terminals.

To show the effect of capacity the transformer was replaced by a condenser. Following are the tables and plotted curves for several conditions.

TABLE FOR CURVE OF E.M.F.

Exciting current 2.5 amperes. No load.

Degrees	Voltmeter readings (a)	(b)	Av.	Instantaneous pressure
0	0	0	0	0
10	+ 6.5	+ 7	+ 6.75	+ 33.25
20	15	15.5	15.25	76.25
30	34	34	34	170
40	43	41	42	210
50	50	50	50	250
60	16	18.5	17.2	86
70	7	7	7	35
80	0	0	0	0
90	0	0	0	0
100	- 7	- 6.9	- 7	- 35
110	18	18	18	90
120	34.1	34.8	34.5	172.5
130	46	45	45.5	227.5
140	48.3	46	47	235
150	13	13	13	65
160	7	7	7	35
170	0	0	0	0
180	+ 3.5	3.4	3.5	17.5
190	7	4	5.5	27.5
200	12.5	13	12.7	63.5
210	24.5	24.8	24.65	122.2
220	43.8	44	43.9	220
230	48.8	49	48.9	245
240	23	23	23	115
250	7	7	7	35
260	0	0	0	0
270	0	0	0	0
280	- 7	/- 7	- 7	- 35
290	10	7	8.5	42.5
300	24.6	24.8	24.7	125
310	45	45.5	45.25	226.5
320	47	49	48	240
330	30	30	30	150
340	7	7.2	7.1	35.5
350	4	7	5.5	27.5
360	0	0	0	0

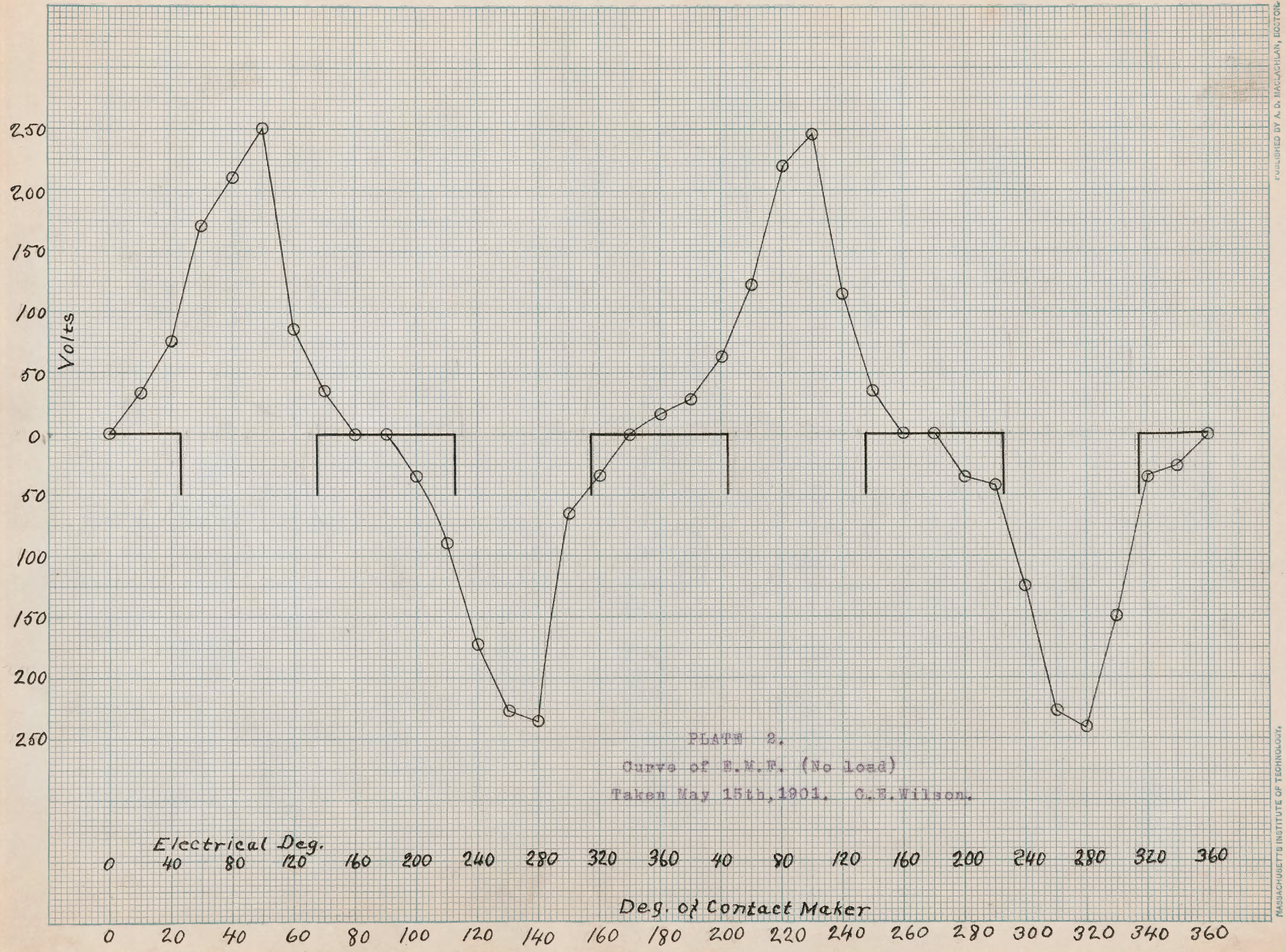


PLATE 2.
Curve of E.M.F. (No load)
Taken May 15th,1901. C.E.Wilson.

TABLE FOR CURVES OF E.M.F. AND CURRENT

Inductive Load. Field current 2 amperes. Armature voltage 95.

Temperature of transformer rose from 23°C to 58°C.

Deg. con. mak.	Voltmeter readings for pressure. (A)	(B)	(Av.)	Actual pressure volts	Voltmeter readings for current. (A)	(B)	(Av.)	Actual current. Amperes.
0	0	0	0	0	- 2.4	2.6	- 2.5	- 12.5
10	+7.2	+7.3	+7.25	+ 37.25	+ 2.6	2.0	2.3	11.5
20	7.0	7.0	7.0	35.0	.8	1.0	.9	4.5
30	18.0	16.0	17.0	85.0	.3	.3	.3	1.5
40	37.0	39.0	38.0	190.0	0	0	0	0
50	44.0	46.0	45.0	225.0	+ .7	.7	+ .7	+ 3.5
60	10.0	7.0	8.5	42.5	1.5	1.7	1.6	8.0
70	7.0	4.0	5.5	27.5	2.0	1.9	1.95	9.75
80	4.0	3.0	3.5	17.5	2.6	2.4	2.55	12.75
90	0	0	0	0	2.6	2.4	2.5	12.5
100	-15.0	18.0	-16.5	- 82.5	1.8	2.0	1.9	9.5
110	34.0	34.5	34.25	171.25	.6	.7	.65	3.25
120	40.0	46.0	43.0	215.0	.3	.3	.3	1.5
130	16.0	16.0	16.0	80.0	.1	-.1	- .1	- .5
140	5.0	7.0	6.0	30.0	- .75	.75	.75	3.75
150	2.0	4.0	3.0	15.0	1.25	1.3	1.28	6.4
160	0	0	0	0	1.8	1.8	1.8	8.5
170	+ 3.0	3.0	+ 3.0	+ 15.0	2.0	2.0	2.0	10.0
180	7.0	7.0	7.0	35.0	1.8	1.8	1.8	9.0
190	13.0	16.0	14.5	72.5	1.5	1.6	1.55	7.75
200	23.0	23.0	23.0	115.0	.85	.9	.875	4.375
210	39.0	39.0	39.0	195.0	.3	.3	.3	1.5
220	26.0	30.0	28.0	140.0	0	0	0	0
230	11.0	7.0	9.0	45.0	+ .35	.3	.325	+ 1.625
240	3.0	3.0	3.0	15.0	.9	.8	.85	4.25
250	0	0	0	0	1.3	1.1	1.2	6.0
260	- 3.0	2.0	- 3.5	- 17.5	1.7	1.6	1.65	8.25
270	7.0	7.0	7.0	35.0	1.7	1.7	1.7	8.5
280	13.0	11.0	12.0	60.0	1.3	1.5	1.4	7.0
290	25.5	25.5	25.5	127.5	.85	.9	.875	4.375

TABLE FOR CURVES OF E.M.F. AND CURRENT.

(Continued).

Deg. con. mak.	Voltmeter readings for pressure.			Actual pressure volts	Voltmeter readings for current.			Actual current amperes
	(A)	(B)	(Av.)		(A)	(B)	(Av.)	
300	35.0	35.0	35.0	175.0	.3	.5	.4	2.0
305	38.0	40.0	39.0	195.0	0	0	0	0
310	34.0	32.0	33.0	165.0	0	0	0	0
320	15.0	15.0	15.0	75.0	- .5	- .3	- .4	- 2.0
330	7.0	7.0	7.0	35.0	.9	.7	.8	4.0
340	3.0	3.0	3.0	15.0	1.5	1.2	1.35	6.75
350	0	0	0	0	1.7	2.1	1.9	9.5
360	0	0	0	0	2.2	2.4	2.3	11.5

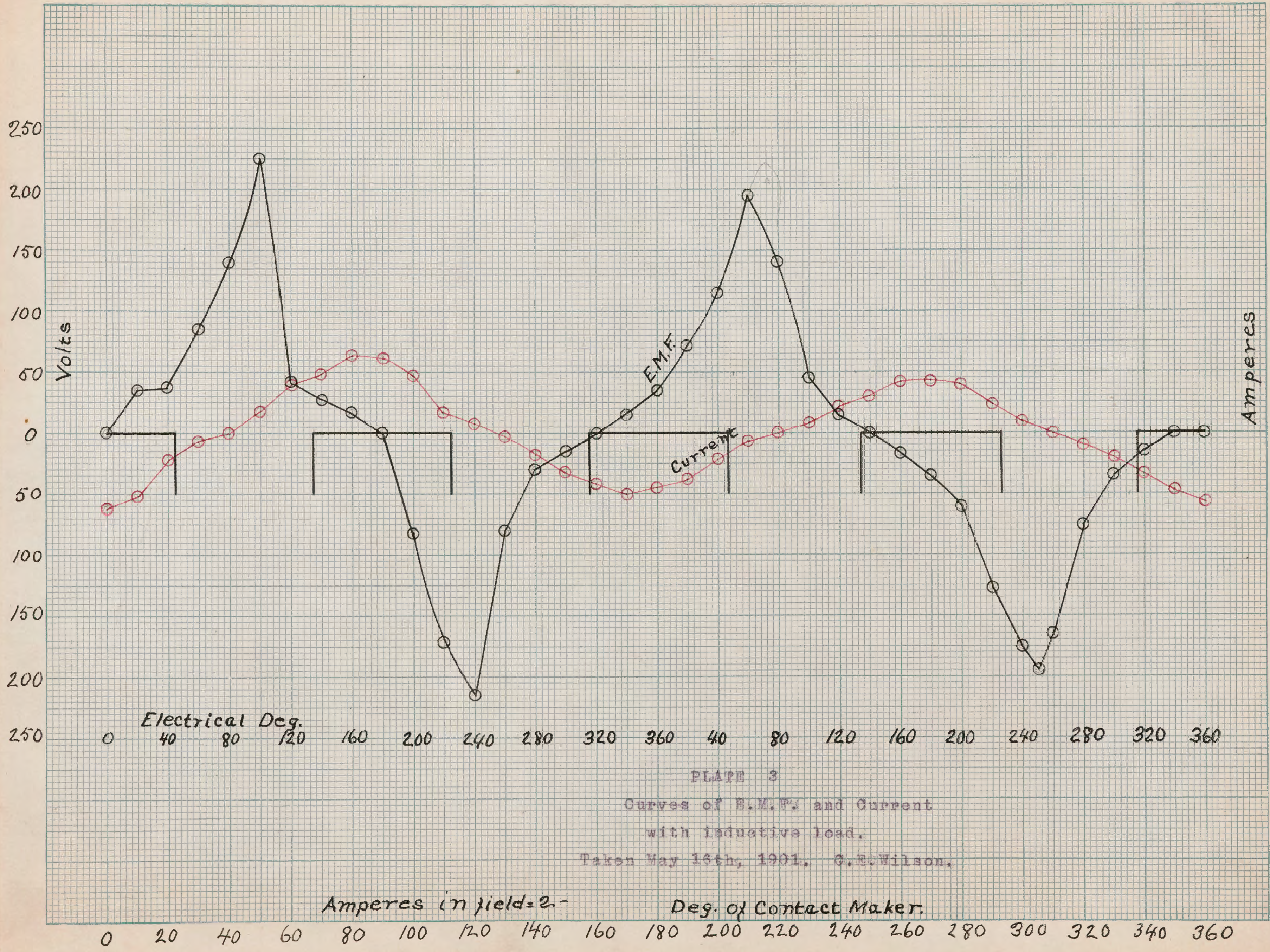


PLATE 3

Curves of E.M.F. and Current

with inductive load.

Taken May 16th, 1901. G. E. Wilson.

TABLE FOR E.M.F. CURVE (Capacity in load)

Field current 2 amperes Voltage at brushes 148

Degrees	Voltmeter readings (a)	(b)	Av.	Instantantaneous pressure
0	0	0	0	0
10	+ 11	+ 7	+ 9	+ 45
20	20	18	19	95
30	55	53	54	270
40	49	50	49.5	247.5
50	60	58	59	295
60	19	16	17.5	87.5
70	11	8	9.5	47.5
80	0	0	0	0
90	- 1	- 1.5	- 1.25	- 6.25
100	11	8	9.5	47.5
110	20	20	20	100
120	48	50	49	245
130	42	38	40	200
140	48	45	46.5	232.5
150	18	15	16.5	82.5
160	8	8	8	40
170	0	0	0	0
180	0	0	0	0
190	+ 7.5	+ 8	+ 7.75	+ 38.75
200	19.5	19.5	19.5	97.5
210	46	48	47	235
220	45	45	45	225
230	40	42	41	205
240	18	15	16.5	82.5
250	8	8	8	40
260	0	0	0	0
270	0	0	0	0
280	- 7.5	- 7.5	- 7.5	- 37.5
290	22	17	19.5	97.5
300	48	51	49.5	247.5
310	48	46	47	235
320	50	48	49	245
330	15	18	16.5	82.5
340	11	8	9.5	47.5
350	0	0	0	0
360	0	0	0	0

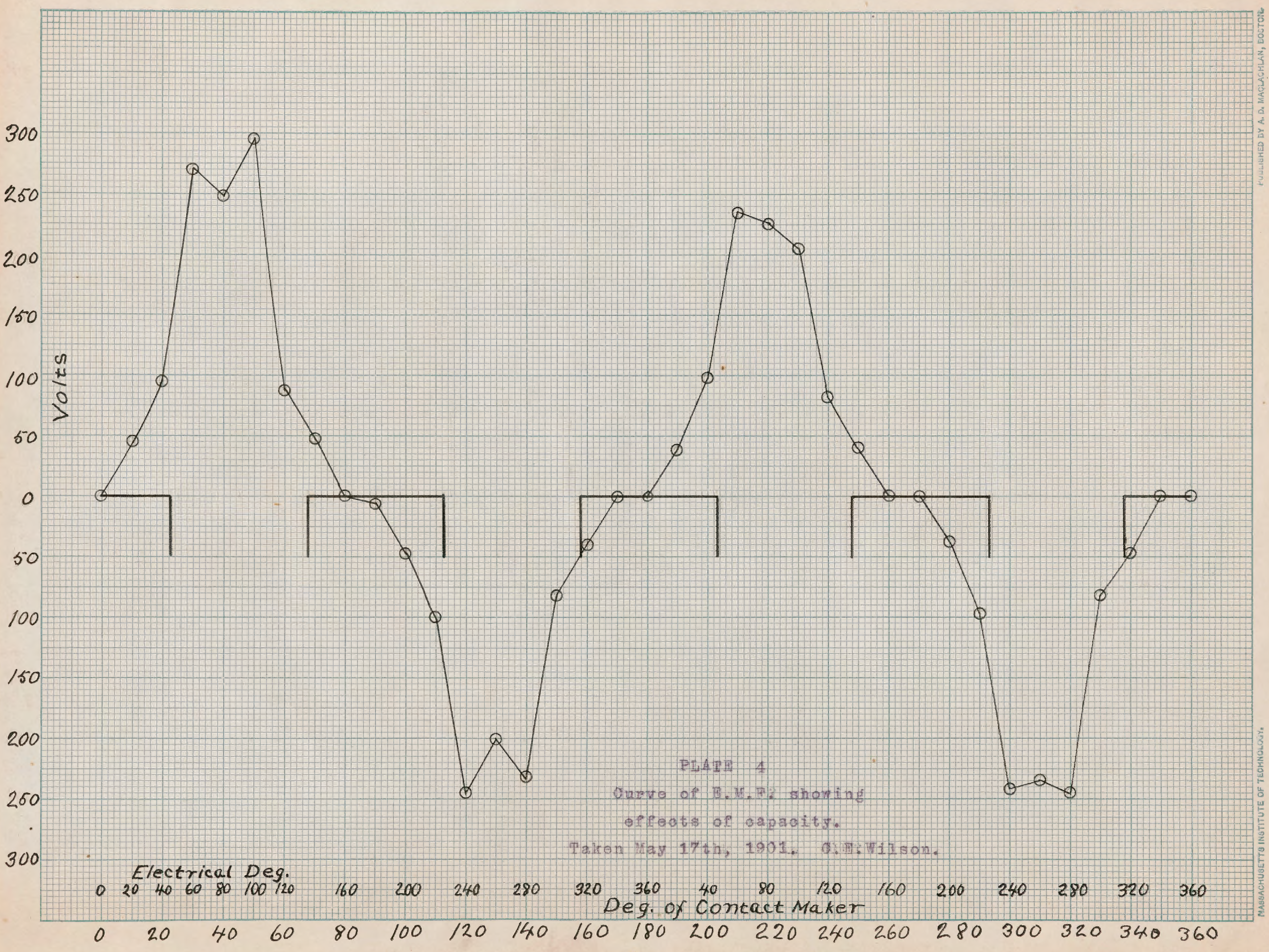


PLATE 4
Curve of E.M.F. showing
effects of capacity.
Taken May 17th, 1901. G.H.Wilson.

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The comparison and study of the E.M.F. curves from this machine is quite interesting. First noticing the E.M.F. curve with no load (Plate 2) we find that the highest pressure is when the armature pole center has just passed the center of the space between the poles, and when armature and field poles are opposite the pressure is zero.

The pressure is zero at this point on account of differential action and is highest when in the other position because there the lines of force are all piled up on the adjacent pole corners making the magnetic flux very strong. In the first case the lines of force are more apt to pass through the armature to a directly opposite pole while in the latter position they probably pass to an adjacent pole rather than through the armature iron, although in each case some no doubt go each way.

The increase of of magnetic flux at this particular point is very large and I attribute the sudden jump up and down to be caused by the majority of the lines of force changing thier direction from opposite poles to adjacent poles and vica versa.

While the pole of armature is moving accross the face of the field pole and the lines of force are going directly through the armature there is little or no pressure, but as the lines of force change direction and the pressure makes a sudden jump up there is caused a very noticeable shoulder on the curve at about 40 and 120 electrical degrees.

In plate 3 there is an entirely different state of affairs for here we have the pressure leading the current, due to an inductive load, and so when the pole faces of armature and field are opposite there is a current flowing which is almost a maximum and it is in such a direction that it tends to weaken the field by setting up an opposing magnetic effect. Consequently the pressure does not reach so high a maximum and the shoulder is more marken as the curve stays longer at low pressure points. The curve also comes to a sharper top which may be attributed to the piling up of the lines of force being reduced to a smaller angle than in the other cases.

In this case the pressure comes to a maximum a little earlier than in the case of no load reaching its highest point just before the current reaches its zero point.

In plate 4 we have a load containing capacity which tends to make the current curve lead the curve of E.M.F. in phase and although the current was too small to be measured by the fall of pressure method still its effects may be noted in the pressure curve.

When the poles of armature and field are opposite there is a current flowing in advance of the E.M.F. which tends to strengthen the fields, consequently the curve of pressure rises more abruptly from the zero position, there being less of a shoulder, and reaches a higher maximum than in either of the other cases.

Rising earlier it reaches the high pressure points sooner than in the other curves and consequently remains longer in the high pressure neighborhood.

These curves show irregularities which may be attributed to several causes among which is the fact that there were two not very rigid couplings on the alternator shaft, one between the armature and contact maker and the other between the armature and motor. Also the contact maker was slightly eccentric to the shaft.

There was also probably more or less error in determining the exact balancing pressure.

On the whole the curves are fairly uniform and illustrate some of the peculiarities of alternating currents.

The last experiment was the determination of External Characteristic curves with inductive and non inductive loads.

The armature was connected the same as in the preceding experiments and an exciting current of 2 amperes used.

The current was measured with the Queen electrodynamometer and the pressure with the electrostatic and Cardew voltmeters. The voltmeter readings were corrected as in the case of the magnetization curve. The electrodynamometer constants were found to be 1.1 for the heavy current connection and .193 for the light.

The bank of lamps was used for a non inductive load and different arrangements of Beylands transformer coils for the inductive load.

The two curves run very much alike in this experiment as is shown by the points on plate 5.

TABLE FOR EXTERNAL CHARACTERISTICS (non inductive load).

Exciting current 2 amperes. Speed constant. (1000 RPM)

Volts	Dynamometer	Current
140	0	0
124	11	3.63
107	33	5.74
100	43	6.55
89	74	8.6
83	85	9.2
75	101	10.0
70	111	10.5
65	121	11
60	133	11.5
57	146	12.0
55	156	12.5
48	178	13.3
40	206	14.3
0	329	18.1

TABLE FOR EXTERNAL CHARACTERISTIC. (Inductive load).

Exciting current 2 amperes Speed constant at 1000 r.p.m.

Volts	Dynamometer	Current	Transformer connections.
142	0	0	Open circuit.
144	5 (l)*	.5	All coils in series.
140	19 (l)	.8	Small coils in series.
138	55 (l)	1.5	Large coil in series with one small.
130	84 (l)	1.8	Small coils in parallel.
133	104 (l)	2.2	One small coil.
108	27 (h)*	5.6	Small coils in series and opposition and in series with large coil.
95	46 (h)	7.4	Large coil.
93	49 (h)	7.6	Large coil in series with and opposition to one small.
55	133 (h)	12.5	Small coils in series and opposition.
15	252 (h)	17.2	Small coils in parallel and opposition.
0	329 (h)	18.1	Short circuited.

(*) The l means the light pressure connection on the dynamometer was used and the h represents the high pressure one.

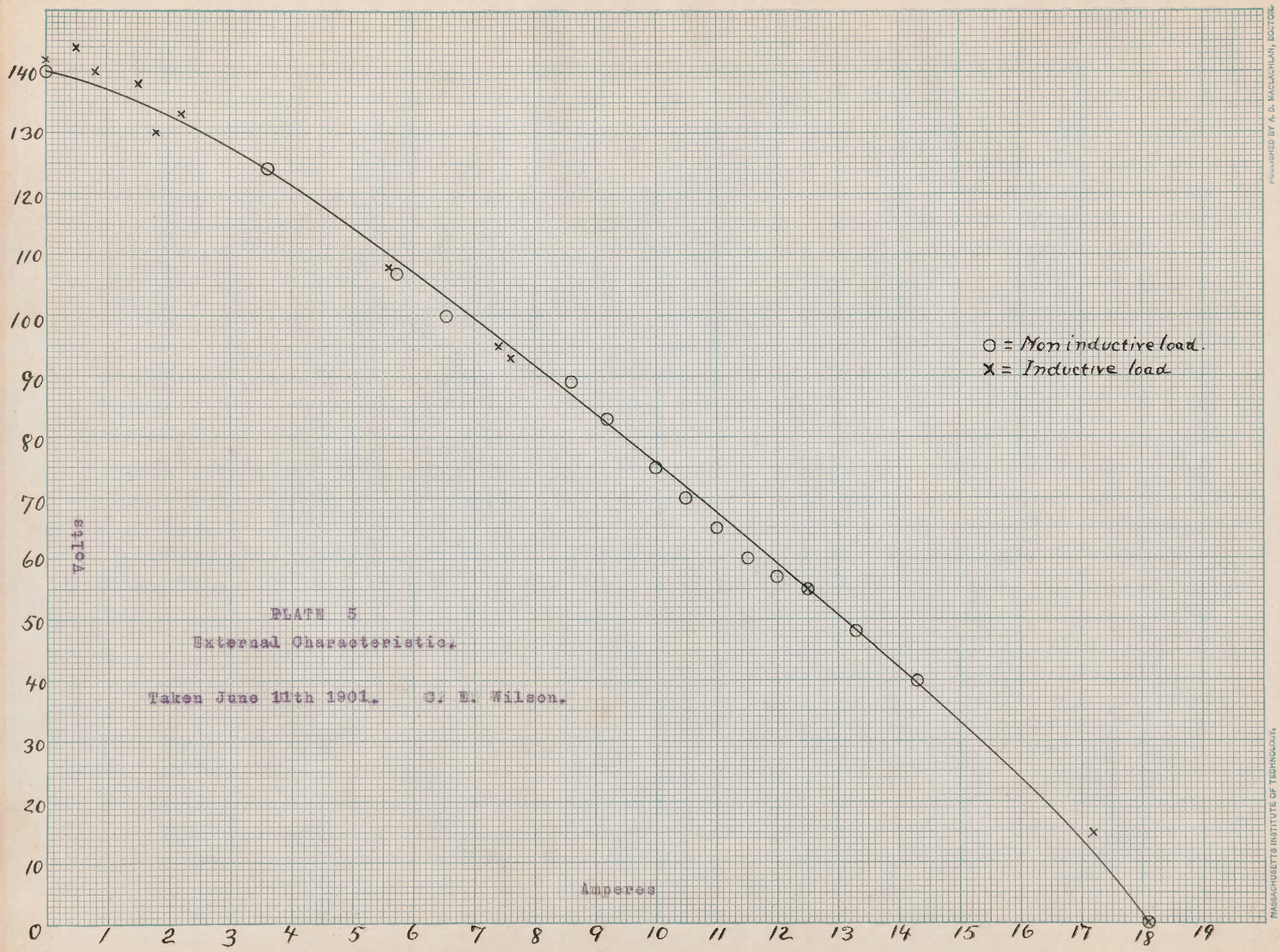

PLATE 5
External Characteristic.

Taken June 11th 1901. C. E. Wilson.