TEST of a 20 K W WESTINGHOUSE GENERATOR

BY

FRED L. W. NORTON

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It is the purpose of this paper to record the data and results of the necessary calculations for a set of tests made on a twenty kilowatt compound interpole type generator, manufactured by Westinghouse Co. The generator is directly connected by a flexible coupling to a thirty horsepower General Electric induction motor.

The Design data of the generator as sent out by the Westinghouse Co. are as follows:

20 K W, 125 Volt, 1750 Rpwr., Frame 83 S K. 40^{o} C, 4 pole

Compound Wound   Two commutating poles.

L - 183465 - A   W A F 731564

D - 190065 - C

Each shunt coil consists of 1241 turns of #18 S.C.C. round wire.

Each series coil consists of $5\frac{1}{2}$ turns of .078" x 1" bare copper strap.

Each communtating coil consists of $21\frac{1}{2}$ turns of 1/8" x 7/8" copper strap, edge wound.

37 armature coils. Each coil consists of 3 single coils with tow conductors in parallel per single coil, ie., a total of six strands per coil. Coils are wound with .0474" by .270 D.C.C. ribbon. Two conductors deep by three wide per coil. Coils lie in slots one and ten. Ends of coils in commutator bars one and fifty-seven. Two circuit progressive continuous windings.

Main pole bore 10-21/32"   commutating pole bore 10-3/4"

Armature diameter 10-1/2"   27 armature slots

Length of armature iron 4" less 3/8" for vent duct.

Inside bore of armature laminations 2-31/32". Outside diameter of axial ventilating passages in armature is 4 1/2" so that depth of active iron below armature periphery is approximately 3".

111 commutator bars   4 straps per bar

Commutator diameter 7"   Length of face 3 3/16"

THE CHARACTERISTIC CURVE:

The Characteristic curve was found as follows:
The generator was driven at constant speed and the field excited so as to give a terminal voltage of 110 volts at no load. The machine was then loaded in suitable amounts by means of rheostats, and the terminal voltage and line current read simultaneously for each step.

This was continued from no load to full load of the machine. The characteristic curve was drawn from these readings with line current as abscissae and terminal voltage as ordinates.

The interpoles of the machine were then taken out of the circuit and a characteristic curve obtained as above described. By a comparison of curves I and II the effect of taking the commutating poles out of the circuit may readily be seen. The terminal voltage went up a little at first and then began to drop off very rapidly. Excessive sparking at the brushes and heating of the commutator prevented the bringing of the machine up to full load current.

DATA FOR THE CHARACTERISTIC CURVES

With Interpoles		Without Interpoles	
Terminal Voltage	Line Current	Terminal Voltage	Line Current
110	0	110	0
113	18	112	20.4
114.3	21.6	112.1	23
115.4	28.4	111.9	27.6
116	31.1	110.4	36
118.7	53.3	106	54
118.5	71	99.1	70
118.2	79	98	72
117.4	92.1	92.6	81
115	120		
112	138	82.6	100
110.6	146		
104	170	77	110

SATURATION CURVE:

The saturation or magnetization curve is a curve showing the relation between the shunt field current and the terminal voltage. To determine this curve the generator was operated at constant speed and on open circuit. The field current was varied in convenient steps from zero to a high enough value to cause the terminal voltage to rise considerably above normal. Readings of the terminal voltage and field current were taken simultaneously for each step. When the highest point was reached the field current was reduced in suitable steps and readings taken for each step. This was continued until the terminal voltage was as low as possible. The ascending and descending curves were plotted using field current as abscissae and terminal voltage as ordinates. It is found that the descending curve is higher than the ascending, or in other words that the same field current gives a higher generated voltage descending than ascending. This is due to hysteresis or the retentiveness of the magnetic flux. Curve III is the curve obtained.

DATA FOR SATURATION CURVE

Ascending		Descending	
Terminal Voltage	Field Current	Terminal Voltage	Field Current
7.9	.048	141	1.803
11.9	.102	136	1.64
14.1	.132	127.3	1.436
16	.156	119	1.27
23.6	.236	110.4	1.14
43	.435	99.4	1.00
55.2	.56	90.3	.883
63.3	.641	81.3	.78
72.9	.736	64.4	.601
81.9	.85	46.5	.42
90	.932	35.5	.307
99	1.043	26	.214
104.8	1.123	19.2	.150
113.6	1.26	12	.08
118.5	1.322	10.4	.06
124	1.42		
130.5	1.554		
133.4	1.61		
141	1.803		

EFFICIENCY CURVE

To obtain the efficiency of a generator the various losses in the machine must be known. The losses are as follows:

(1) The copper loss in the armature.

(2) The copper loss in the series field.

(3) The copper loss in the shunt field.

(4) The brush contact loss.

(5) The stray power losses which include

 (a) Mechanical friction.

 (b) Eddy current loss.

 (c) Magnetic Hysteresis loss.

The above losses were determined as follows:

(1) Current was passed through the armature windings and the value of the current and the voltage drop in the armature were measured simultaneously by voltmeter and ammeter. The resistance was then calculated by use of the formula $R = \frac{E}{I}$ The loss is $R I^2$ watts.

Armature resistance data

E_a	I_a	R_a
.15	5.99	.0250
1.2	48	.0250
.204	8.1	.0252
1.843	74.3	.0248
	Average R_a	.0250

(2) The resistance of the series field was found by the same method that the armature resistance was found.

E_{sf}	I_{sf}	R_{sf}
.1465	36	.00407
.183	45	.00407
.200	49	.00408
.244	60	.00406
	Average R_{sf}	.00407

$(2)_a$ Resistance of interpole winding

E_i	I_i	R_i
.1082	27.3	.00396
.140	36.0	.00389
.170	43.1	.00395
.213	53.9	.00395
.320	80.0	.00400
	Average R_i	.00395

The series field winding and the interpole winding of the generator together are the series windings of the generator. Thus the resistance of the series winding is:

$$R_s = .00407 + .00395 = .00802 \text{ ohms.}$$

(3) The resistance of the shunt field winding was found by the fall of potential method as the above resistances were found.

E_f	I_f	R_f
39.9	.77	51.8
45	.87	51.7
50	.97	51.6
55.7	1.075	51.7
	Average R_f	51.7

(4) The brush contact resistance has been found to vary practically inversely with the current, thus making the drop nearly constant regardless of load. The Standard Handbook of Electrical Engineering gives this deop as one volt per brush thus making a drop of two volts for two brushes. The loss due to the brush contact resistance is then E_b I_a Watts.

(5) In order to determine the stray power losses the generator was disconnected from its prime mover and operated as a motor. The power consumed when the generator is running as a motor without any load and at the rated speed is the power required to overcome the different losses which come under the head of stray power losses. The generator while running as a motor and at its rated speed was found to require 9.6 amperes at 110 volts, thus giving a stray power loss of 110 x 9.6 = 1056 watts. * This loss does not vary with the load on the machine but remains constant at all loads.

* As load comes on, the series field carry heavier currents so that the stray power losses increase with load. Certain other "load losses" increase it also.

Data and derivation of results for the efficiency curve are as follows: The different loads were assumed.

Watts	E_t	I_a	I_a^2	I_f	I_f^2	$E_b I_a$	$I_a^2 R_a$	$I_f^2 R_f$	$I^2 R_s$	Stray Pwr.	Total Loss	% Eff.
2000	125	16	256	1.44	2.07	32	6.4	107	2.05	1056	1203.5	62.4
4000	"	32	1024	"	"	64	25.6	"	8.2	"	1260.8	76
6000	"	48	2304	"	"	96	57.6	"	18.5	"	1335	81.8
8000	"	64	4096	"	"	128	102.3	"	32.8	"	1426	84.6
10000	"	80	6400	"	"	160	160	"	51.3	"	1534	86.6
12000	"	96	9216	"	"	192	230	"	73.8	"	1659	88
14000	"	112	12544	"	"	224	314	"	100.5	"	1801	88.5
16000	"	128	16384	"	"	256	410	"	131.3	"	1960	89
18000	"	144	20736	"	"	288	518	"	166.2	"	2135	89.4
20000	"	160	25600	"	"	320	640	"	205	"	2328	89.5

DISTRIBUTION OF POTENTIAL AROUND ARMATURE

Sparking and brush displacement depend to a considerable extent upon field distortion in the air gap, due to the armature current. This effect was investigated by taking a series of readings around the commutator by the aid of a pilot brush.

One terminal of a voltmeter was connected to one of the brushes of the machine and the other to a small auxiliary brush, a steel pen point in this case, which could be moved around the commutator. Its position relative to the main brushes was determined by means of a graduated arc made of thin fiber board and fastened so as to fit around the end of the commutator. The machine was run at normal spped and terminal pressure. Pressure readings were taken at angular intervals corresponding to the angular interval of commutator bars. The increments of pressure, as the pilot brush was moved around the commutator, were the pressures in the armature coils that were added to the voltmeter circuit. Since the angular distance the brush was moved was constant, the pressures were directly proportional to the average magnetic induction in which the added armature coils were passing.

The accuracy of this method is somewhat impaired because of the variable position of the pilot brush with reference to the commutator bars, the pressure indicated being an average for the given position of the brush. It should also be noted that the voltmeter readings are due to conductors lying under two poles and therefore the distribution curve shows the averages of distributions under two poles. Readings were taken half way around the commutator or from one plus brush to the other plus brush.

DATA FOR CURVE

Commutator Bar No.	E. M F.
1	-.4
2	-.23
3	.033
4	.56
5	2
6	4.5
7	8
8	11
9	17
10	23
11	29
12	35
13	40
14	46
15	53
16	60
17	66
18	70
19	75
20	80
21	88
22	93
23	96
24	98
25	101
26	103
27	103
28	103
29	102
30	102

DATA FOR CURVE (Cont'd)

Commutator Bar No.	E. M.F.
31	101
32	100
33	98
34	96
35	94
36	88
37	86
38	80
39	75
40	69
41	60
42	55
43	50
44	44
45	38
46	32
47	27
48	22
49	15
50	10
51	7
52	3
53	1.5
54	0
55	-.5
56	-.4

COEFFICIENT OF MAGNETIC LEAKAGE.

The coefficient of magnetic leakage of a generator or motor is the ratio of the amount of flux threading through the pole to the amount threading through the armature. In order to determine this coefficient a coil of four turns of fine wire was placed on the armature so as to aurround all lines of flux passing into it. Four turns of the same kind of wire was wound around the pole. The wires were of the same length so that the resistances would be the same. A millivolt meter was placed in series with the coil on the pole. The field was then excited. A snap switch was placed in the field circuit so that the circuit could be made or broken the same way each time. When the field circuit was made or broken an emf. proportional to the amount of flux passing through the pole was induced in the coil wound around the pole causing a deflection of the millivolt meter. This deflection was noted and recorded for both the make and break contact. The millivoltmeter was then placed in the coil on the armature and the deflection obtained as before. The ratio to the pole deflection to the armature deflection is the coefficient of magnetic leakage.

Deflection in pole coil = 34.3

Deflection in armature coil = 31.5

$$\text{Ratio} = \frac{34.3}{31.5} = 1.09$$

Another method of finding the coefficient is to place the two coils in series so that their emfs. oppose each other and fidn the number of turns in each coil required to give zero deflection of the millivoltmeter.

With four turns in each coil the deflection was 7.8.

With three coils on pole and four on armature the deflection was 16.2 (connections reversed)

$7.8 + 16.2 = 24$

$\frac{7.8}{24} = .325 =$ no. of turns to be taken from pole to give zero deflection.

$4 - 325 = 3.675$

Ratio $\frac{4}{3.675} = 1.089$ which checks with result obtained by other method.

HEAT RUN.

Heat runs are performed to determine whether or not a machine stays within certain specified limits of temperature. In this test thermometers were fastened securely to the field and frame of the machine and their bulbs covered with a small amount of putty. The machine was operated under full load and at normal speed. The run started at 3:55 P.M. and ended at 6:20 P.M. Readings of the thermometers were taken every five minutes throughout the run. When the machine had reached constant temperature, as shown by the thermometers, it was shut down and final temperatures taken of the armature and commutator. Curves were plotted using time as abscissae and rise in temperature of frame and field as ordinates.

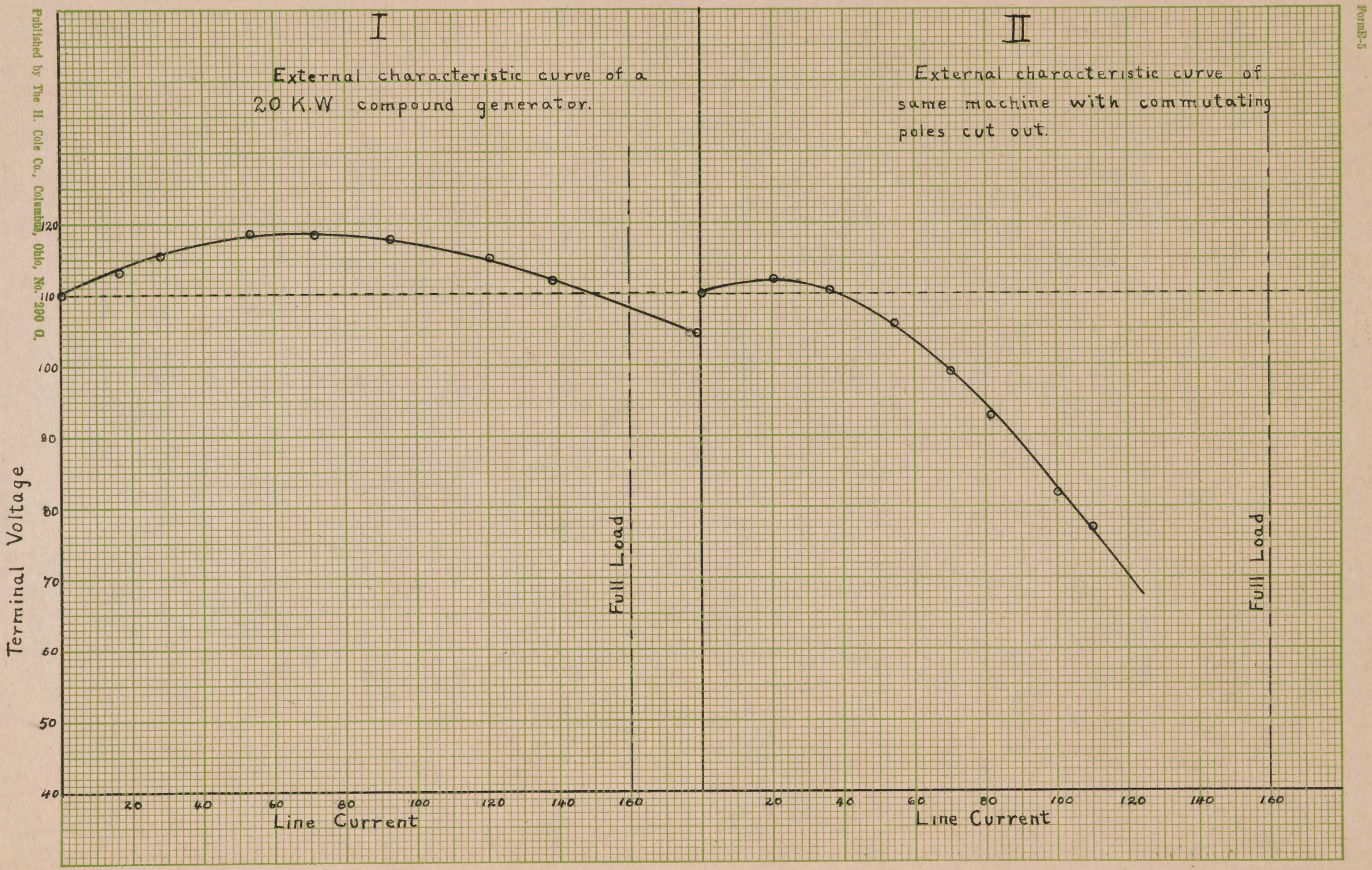
Room temperature at beginning of run	81° F
Temperature of all parts of generator before run was started	81° F
Temperature of armature at end of run	136° F
Temperature of commutator at end of run	145° F
Rise in temperature of armature	55° F
Rise in temperature of commutator	64° F

The greatest rise in temperature was in the commutator. This rise was 35.5° C. Since the specified rise in temperature of the mqchine is 40° C, the above value shows that it could be run at somewhat over-load without over heating the commutator. The temperature of the other parts of the machine fell considerably below the commutator temperature as is shown by the curves.

The behavior of this machine as a whole is very satisfactory. The vibration becomes excessive at times but this, no doubt, is due to faulty installation and not to any eccentricity in the machine itself.

DATA FOR CURVES

TIME	POLE Temperature	FRAME Temp.	TIME	POLE Temperature	FRAME Temp.
3:55	81	81	5:40	133.8	116.5
4:00	85	81	5:45	134	116.5
4:05	93.8	82	5:50	134.5	117
4:10	100	84.3	5:55	135	117.2
4:15	106	88.2	6:00	135.4	117.5
4:20	110	91.6	6:05	135.8	118
4:25	113.7	95	6:10	136	118.6
4:30	116.3	98	6:15	136	119
4:35	119.3	100	6:20	136	119
4:40	121.5	102.6	6:25		
4:45	123.3	105			
4:50	124.6	108.2			
4:55	126				
5:00	127	109.8			
5:05	128	111.2			
5:10	129.5	112			
5:15	130.4	113			
5:20	131.4	113.8			
5:25	132	114.8			
5:30	132.8	115.6			
5:35	133.4	116			


I
External characteristic curve of a 20 K.W compound generator.
II
External characteristic curve of same machine with commutating poles cut out.
Terminal Voltage
120
110
100
90
80
70
60
50
40
20
40
60
80
100
120
140
160
Full Load
Line Current
Full Load
Line Current
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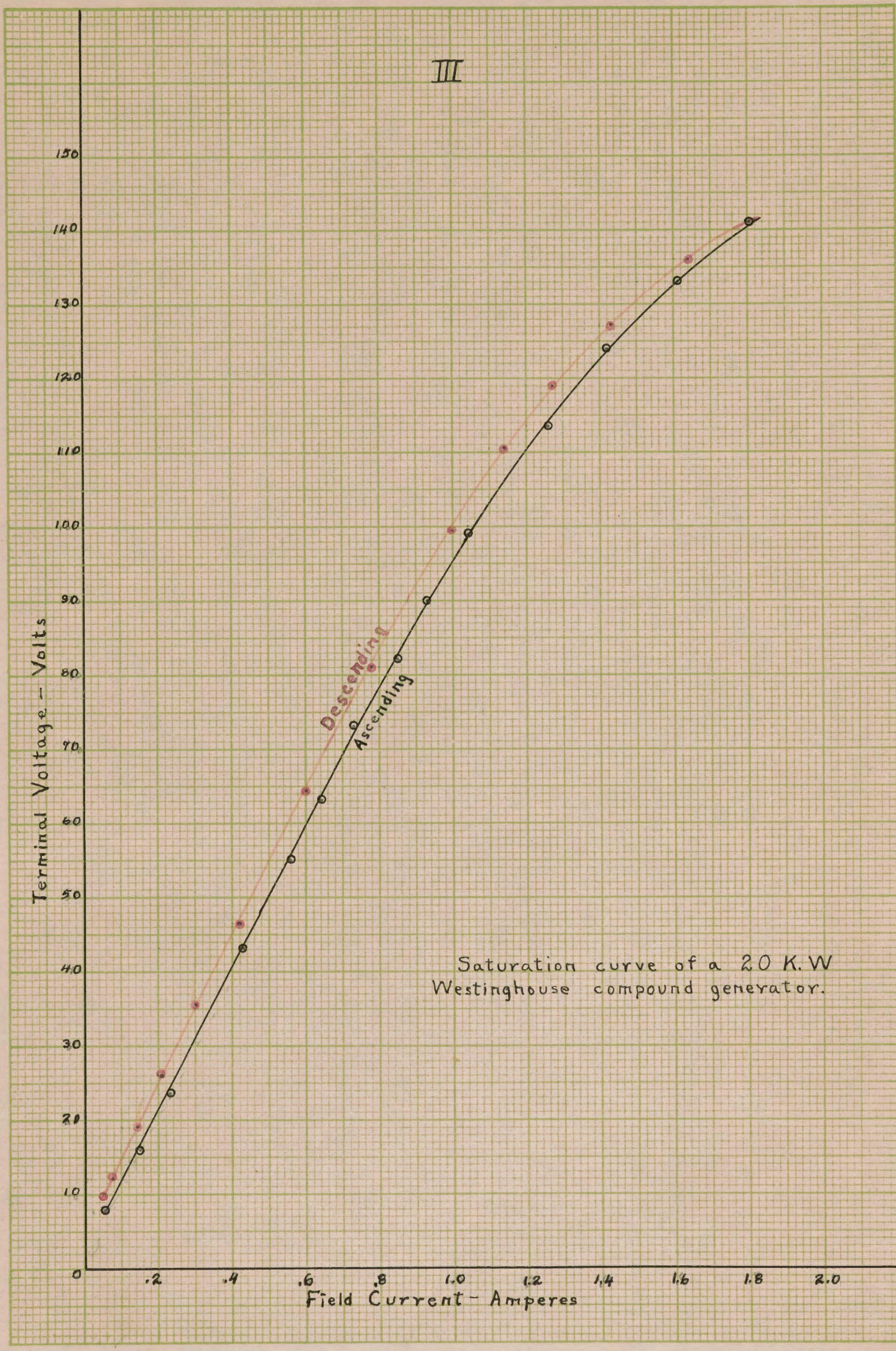
Form E-5



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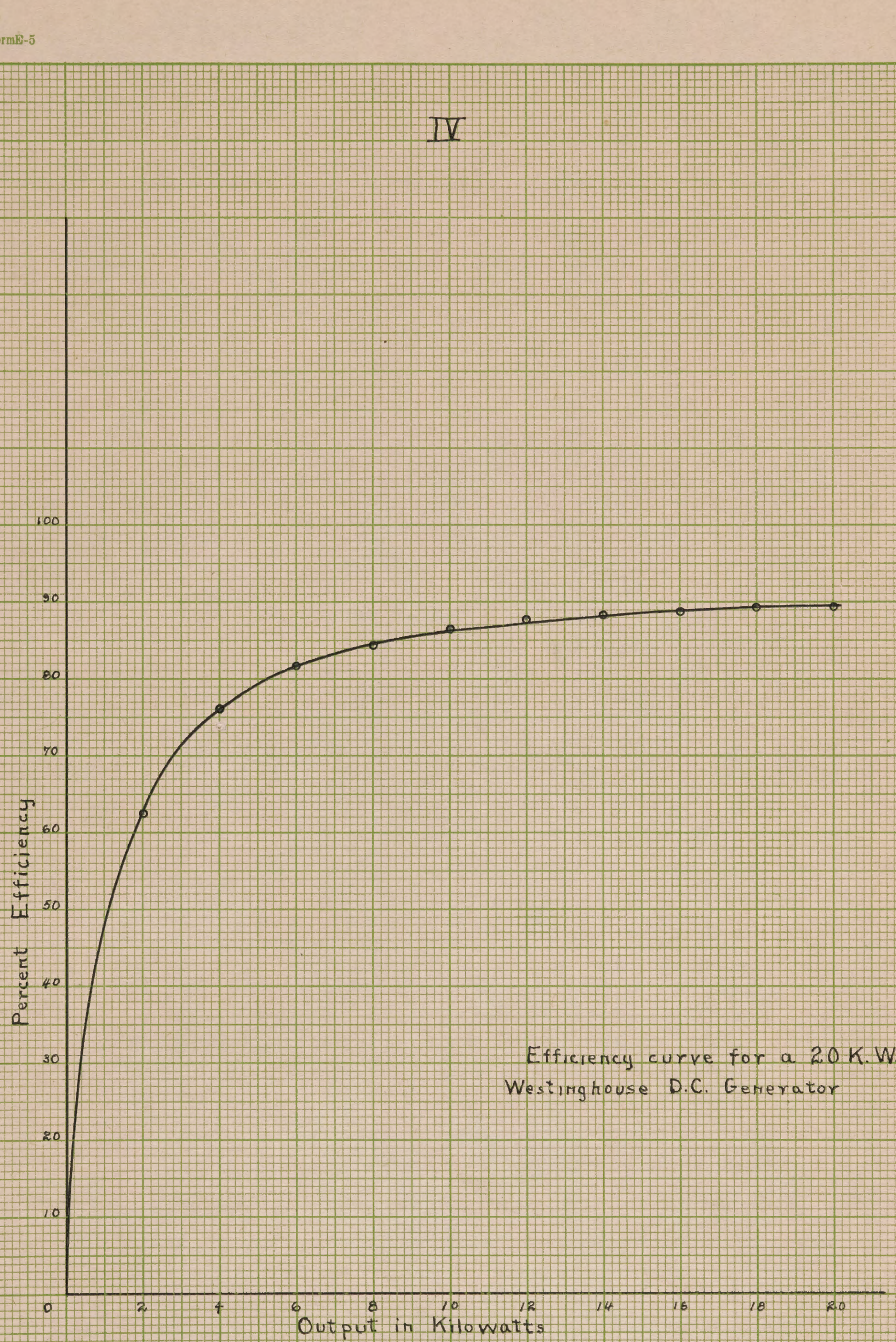
Form E-5

IV



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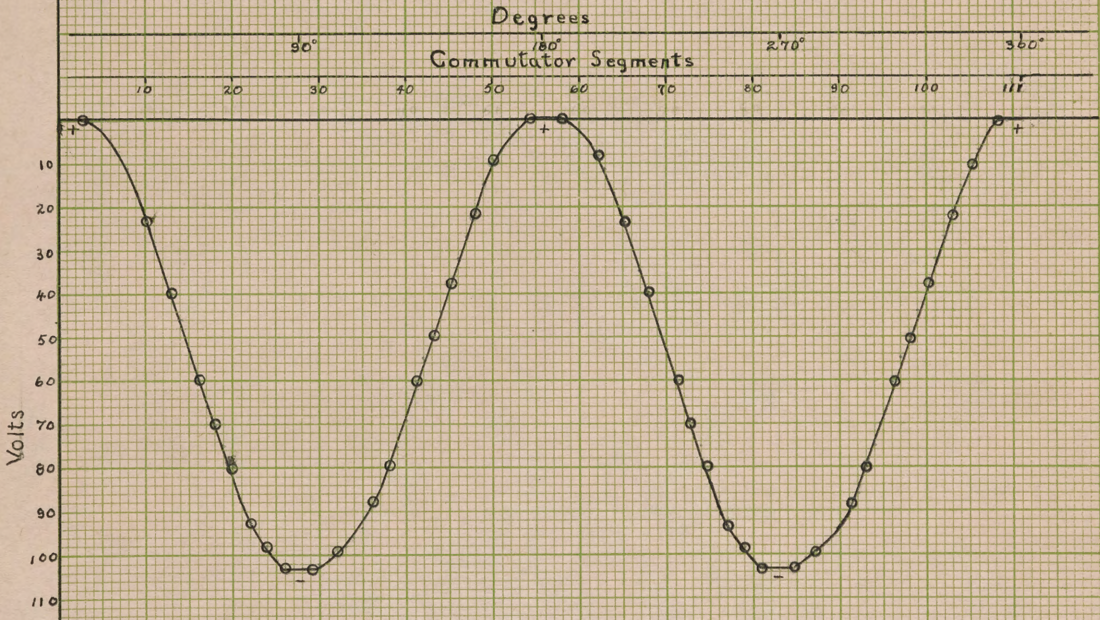
FormE-5

V

Curve showing the distribution of potential around armature of a 20 K.W. Westinghouse compound generator.



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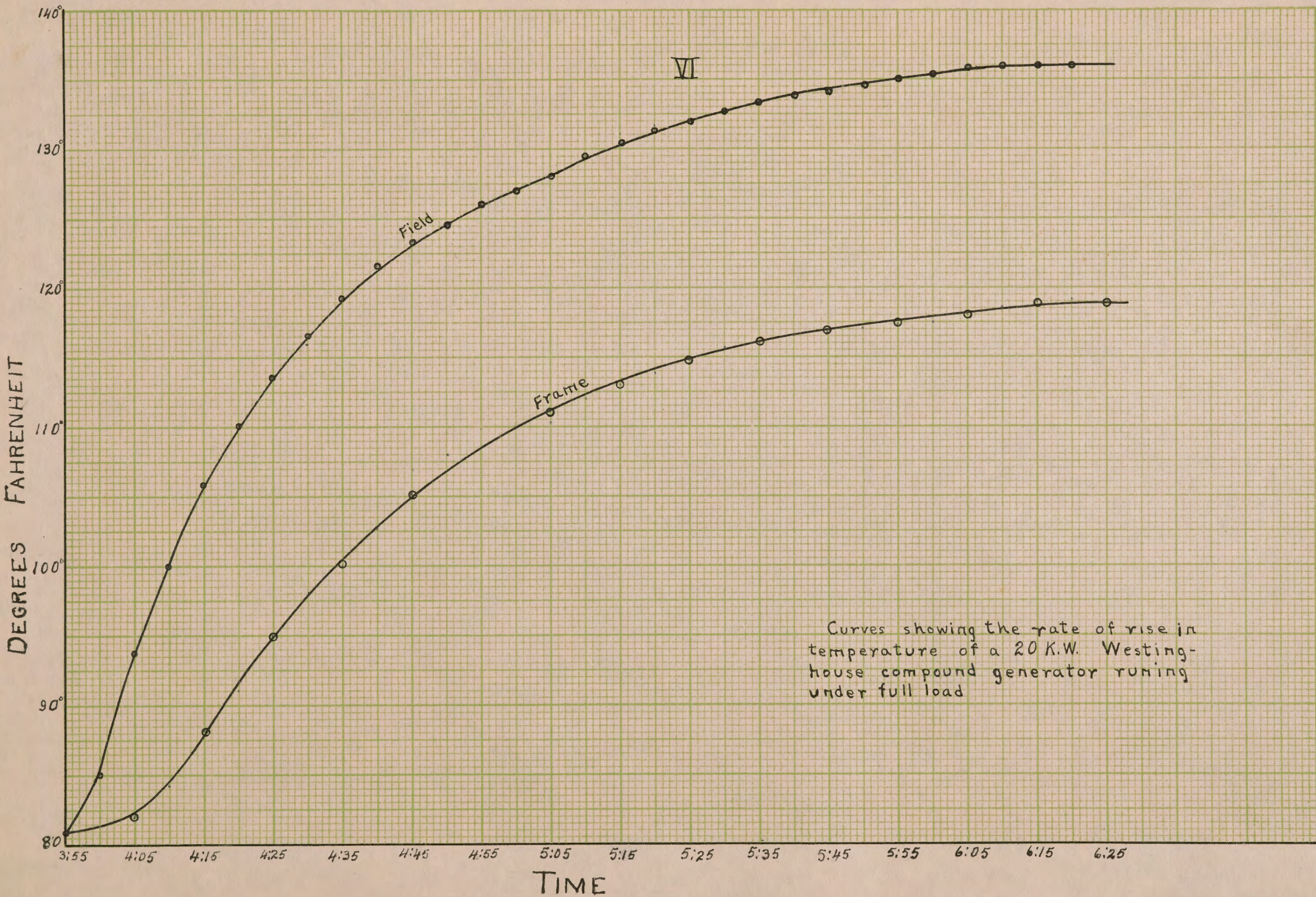

Curves showing the rate of rise in temperature of a 20 K.W. Westinghouse compound generator running under full load

APPROVAL

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NAME Chas A Perkins

TITLE Professor Electrical Engineering.