T H E S I S

on

Tests of a Direct Current Generator

Submitted to the Faculty

of the

O R E G O N A G R I C U L T U R A L C O L L E G E

for the degree of

BACHELOR of SCIENCE

in

ELECTRICAL ENGINEERING

by

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APPROVED..

Department of ELECTRICAL ENGINEERING

INTRODUCTION.

It is necessary before placing any piece of apparatus on the market to thoroughly test it under similar conditions to that for which it was designed, and to rate it accordingly to the results of the tests, allow- a reasonable margin for unusual conditions.

By the aid of our technical and industrial schools now established throughout the land, and the great attention given to the engineering literature by the men successful in practice, the rank and file of electrical workers are becoming educated to a point where they become keenly alive to the relative value and merits of nearly every machine appliance or appurtenance known to the engineering world.

The reason for a need of general understanding of electricity cannot be doubted when it is noted that it lends a hand to every industry wherein natural energy must be transformed, (for electricity is not a prime mover but an agent) to do useful work. That is, to say, that if fuel be the source of natural energy, instead of having boilers and engines or at least engines in every shop, and at every point where mechanical energy must be used, motors that may be placed within a few feet of floor space, or if not unusually large may be fastened to the wall or ceiling, are placed at these points and the boilers and engines are placed together and at a place where their ecomomical operation is greatly enhanced. Or if water power is to be utilized, generators may be connected to the shaft of the water wheel and the energy transmitted to great distances. Whereas before the advent of the methods of subordinating electricity to the will of man, if the power of the water fall was to be utilized it became necessary that all machinery it was to ~~be~~ operated must be assembled within a few rods of the point where the water acts on its wheel.

Since a dynamo and motor are mutually convertible the tests which follow cover the actions of the machine as a motor as well as a generator.

The machine is of multipolor type, four poles, nine kilowatts at fourteen hundred and fifty revolutions per minute, four brush sets with three carbon brushes per set.

The machine consists of a revolving part, or armature, in which electro-motive forces are induced (generated), and a stationary magnetic field necessary for inducing these electro-motive forces.

The armature is driven by a prime mover whose power is thereby transformed into electrical energy and delivered to the line though the armature terminals. The armature itself consists of a cylindrical iron core, mounted on the shaft and provided with slots on its periphery. A winding consisting of copper coils is placed in these slots. The coils are properly inter-connected so as to assist each other in their electrical action, and are also connected to the so-called commutator shown in the left of the figure. Which commutator converts alternating voltages and alternating currents into direct voltages and direct currents. The commutator consists of copper segments mounted on a sleeve and insulated fax from each other by sheets of mica. Carbon brushes make contact with the copper segments and conduct the current to the line.

The most commonly employed connections between the fieldwindings and the armature are shown in figure 2. The field winding consists of many turns of a comparatively small wire, and is connected across the brushes of the machine.

Self excitation is made possible by virtue of residual magnetism in the frame and pole pieces. When started with the line circuit open, the residual magnetism induces a small current in the armature; this current flows through the field winding and strengthens the original field. This increased field induces stronger currents in the armature which sends a stronger current through the field; this continues until the excitation has reached its full value.

The voltage induced in the armature is proportional to the flux issuing from the pole pieces. The flux depends on the value of the exciting current so that finally the voltage depends on the value of field current.

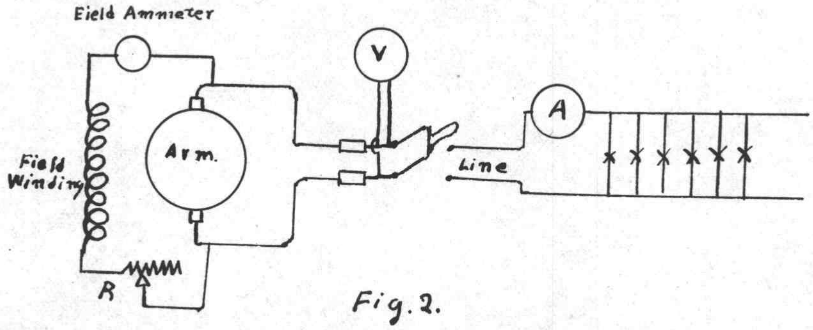

Fig. 2.

This variation of flux is called the no-load characteristic of a shunt wound dynamo and in the case of the machine under consideration conforms to the curve of figure 3. The dynamo being belt driven at a constant speed and connected as per figure 2. The readings were begun with zero field and gradually increased (by means of a rheostat) to the highest possible value and then gradually decreased. The descending curve lies above the other on account of the hysteresis or magnetic retentivity of the iron of the magnetic circuit.

Data for no-load characteristic of a shunt-wound generator.

Field amps.	Volts	Speed	Field amps.	Volts
0	5	1450	.12	126
0	10	1450	.11	123
.04	15	1450	.1	120

.11	20	1450	.9	112
.2	25	1450	.8	103
.24	25	1450	.7	92
.26	35	1450	.6	80
.31	40	1450	.5	70
.34	45	1450	.4	54
.37	50	1450	.3	42
.41	55	1450	.2	31
.44	60	1450	.1	24
.48	65	1450	0	6
.54	70	1450		
.55	75	1450		
.60	80	1450		
.65	85	1450		
.69	90	1450		
.73	95	1450		
.8	100	1450		
.87	105	1450		
.92	110	1450		
.96	115	1450		
1.01	120	1450		
1.2	130	1450		
1.03	125	1450		

Curves are shown in figure 3.

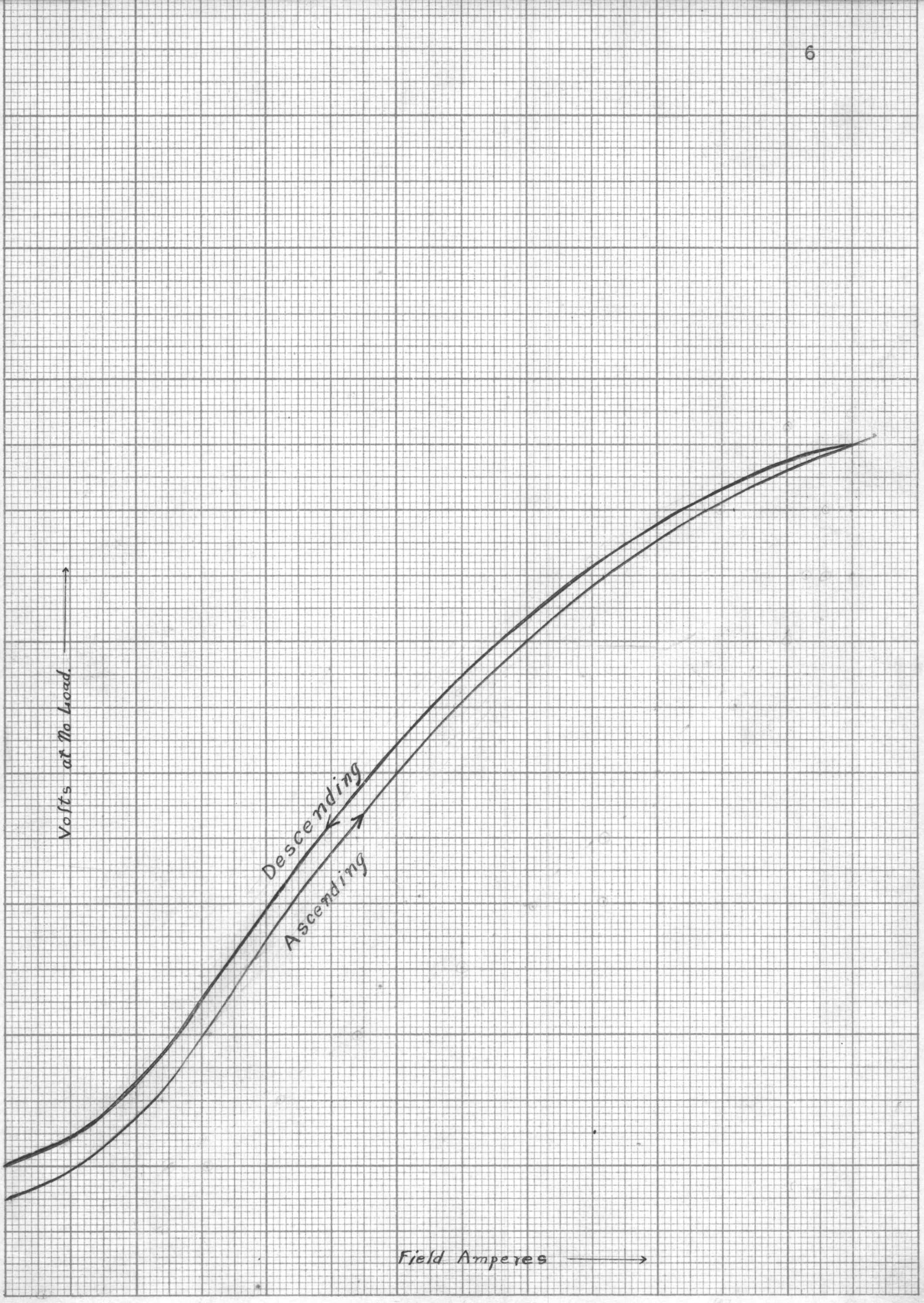

Fig. 3.

One of the most important requirements in practical operation of generators supplying current for light and power is that the terminal voltage must be nearly constantindependently of the load. This means, that each customer should get the same quantity of light from his lamps and the same speed from his motors, whether many or only a few costomers are using current at the same time.

This condition cannot be strictly fulfilled with a shunt-wound generator, unless the field current is regulated by the field rheostat. Without regulation the voltage drops considerably as the load increases. This is due to three causes;

1st. Part of the induced voltage is consumed in the resistance of the armature; this drop (ir) is proportional to the armature current. 2nd. The armature currents tend to produce a magnetizationopposite to that due to the shunt field winding, and in this way weaken s the original field. The voltage induced in the armature is therefore correspondingly lower. 3rd. As the terminal voltage decreases, on account of the above couses, the current in the shund winding also decreases in the same proportion.

The curves figures 4,5, and 6 show the voltage fluctuations of the machine, variations of field, etc., with changes of load.

Data for voltage characteristics of a shunt-wound genatator.

100% of full load.

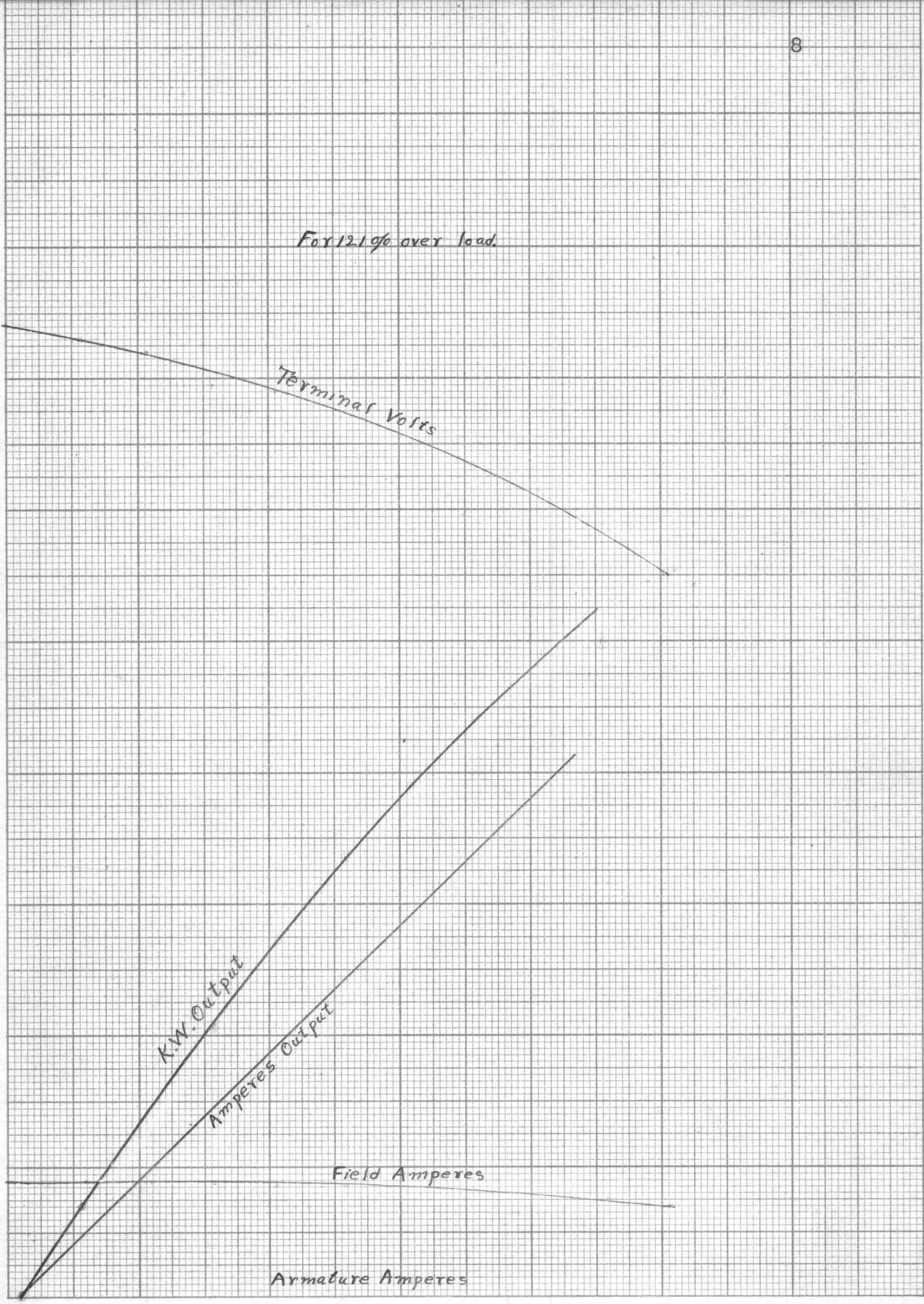
For 121 % over load.
Terminal Volts
K.W. Output
Amperes Output
Field Amperes
Armature Amperes
NO 345
EUGENE DIETZGEN CO. CHICAGO-NEW YORK

Fig. 4.

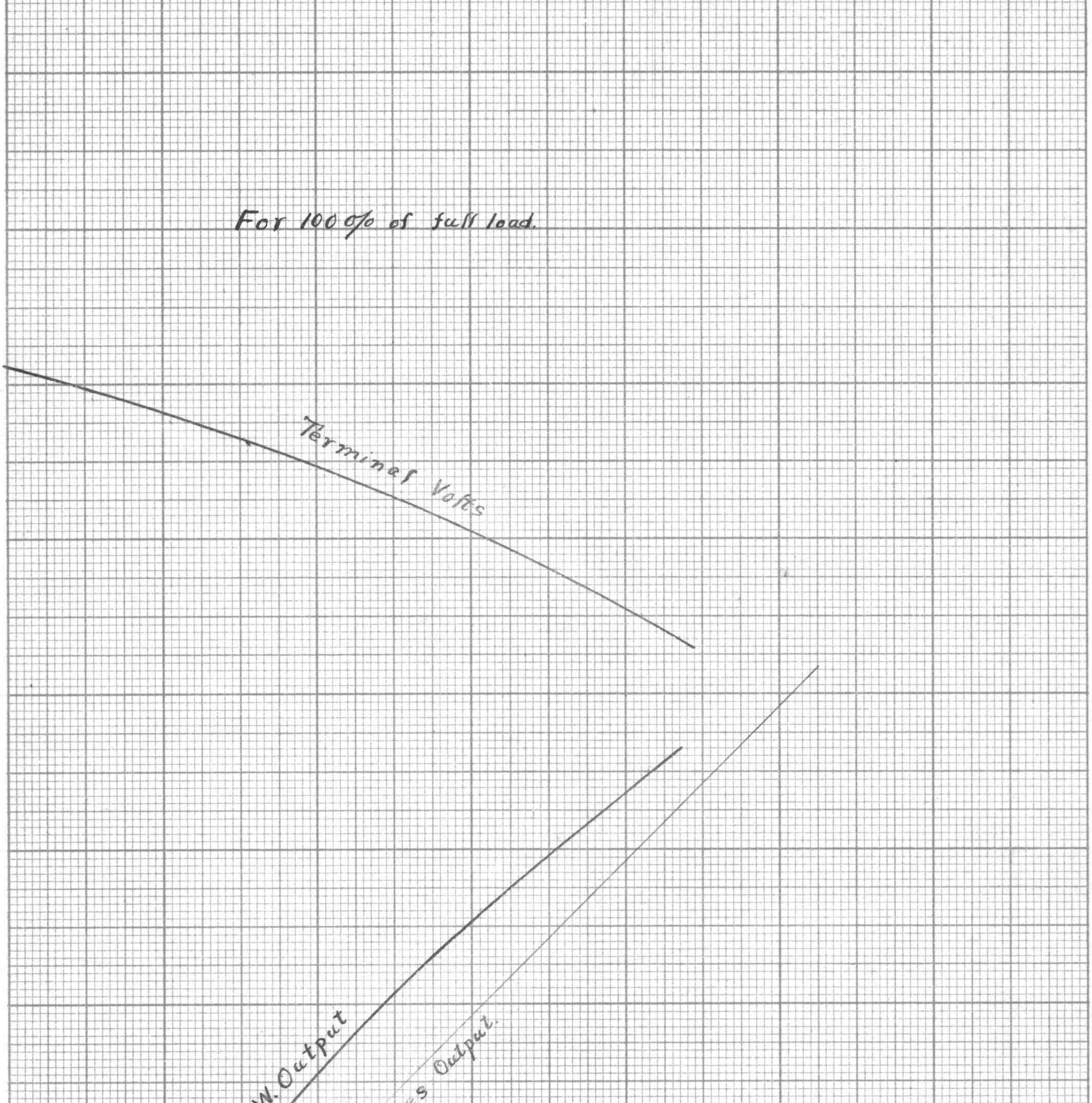
For 100 o/o of full load.
Terminal Volts
K.W. Output
Amperes Output.
Field Amperes.
Armature Amperes.

Fig. 5

Fig. 6

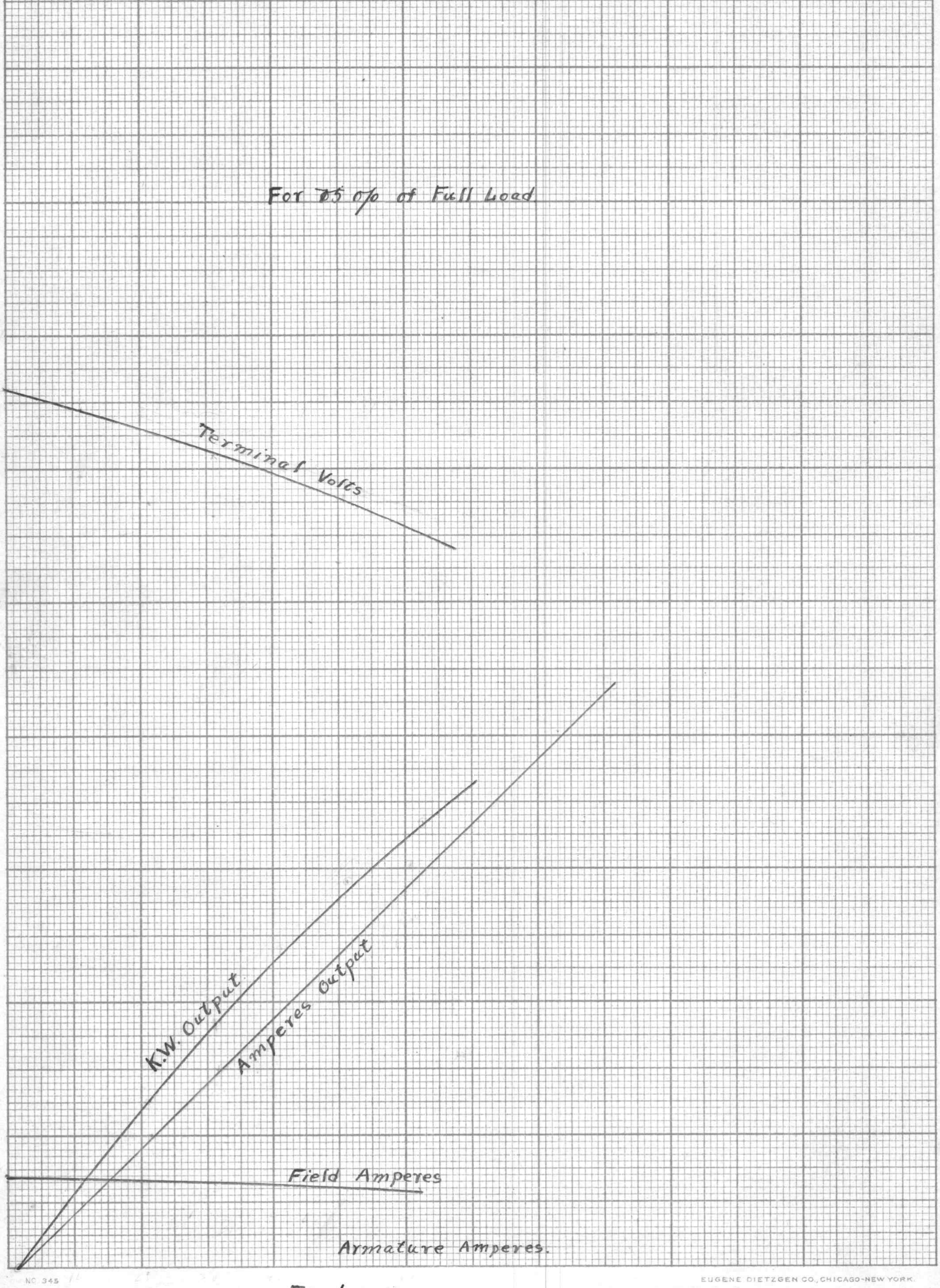
For 75 o/o of Full Load
Terminal Volts
K.W. Output
Amperes Output
Field Amperes
Armature Amperes.

Fig. 6

Field amps.	Load amps.	volts	speed	k.w. output
1.24	82.5	110	1450	9.05
1.31	70	116	"	8.13
1.35	60	120	"	7.2
1.42	50	126	"	6.3
1.45	40	128	"	5.15
1.48	30	132	"	3.94
1.5	20	135	"	2.7
1.55	10	138	"	1.3
1.59	0	142	"	0.
	For 75% of Full Load			
1.15	61.5	110	"	6.7
1.2	50	116	"	5.8
1.24	40	120	"	4.8
1.25	30	123	"	3.68
1.29	20	125	"	2.5
1.33	10	129	"	1.29
1.36	0	132	"	0.
	For 121% over load.			
1.43	100	110	"	11.
1.5	90	118	"	9.9
1.55	80	123	"	9.85
1.6	70	127	"	8.8
1.65	60	130	"	7.8
1.7	50	134	"	6.7
1.73	40	138	"	5.5

1.75	30	139	1450	4.18
1.81	20	144	"	2.48
1.83	10	146	"	1.46
1.83	0	148	"	0.

The curves are shown in figures 5,6, and 4.

To observe the variation of field-current and flux, voltage remaining constant, the generator was connected as figure 2. and brought to an over load of 121%, at the rated voltage, that is, 110, and the load then decreased gradually and readings being taken. The resistance in the field circuit being gradually increased so as to keep the terminal voltage constant.

Percent variation in field current depends on the degree of saturation of the machine. This is evident when we consider that a large number of field ampere turns are required with higher saturation, therefore the same number of armature demagnetizing ampere turns constitutes a smaller percent of the active ampere-turns and its influence is less noticeable.

Data for excitation characteristic of a shunt wound generator.

Field amps.	load amps.	volts	speed	k.w.output
1.28	98	110	1450	10.75
1.25	91	"	"	10.
1.18	80	"	"	8.7
1.13	70	"	"	7.7

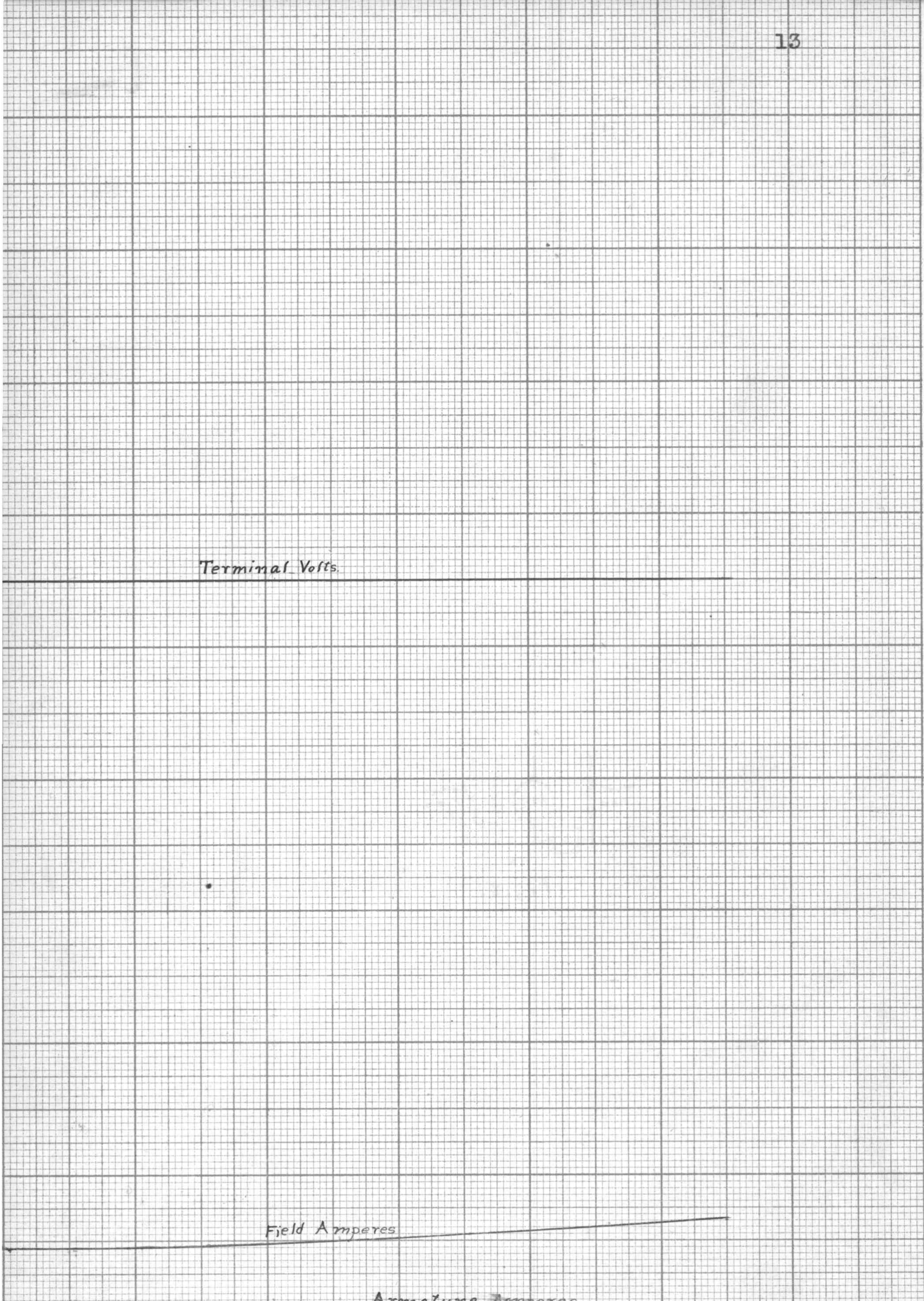

Fig.7

1.04	60	110	1450	6.6
1.03	50	"	"	5.5
1.	40	"	"	4.4
.93	30	"	"	3.3
.905	18	"	"	1.64
.885	10	"	"	.08
.87	0	"	"	0.

The curves are shown in figure 7.

The above two tests show that theterminal voltage of a shunt wound generator decreases as the load increases. In order to keep the voltage constant, it is necessary to either regulate the field rheostat, or obtain the same effect automatically by placing on the pole peieces a second winding, in series with the main circuit. Figure 8.

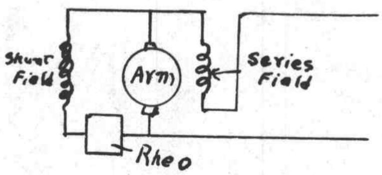

Fig. 8.

As the main current increases more current flows through the series winding, adding excitation to that supplied by the shunt winding. By properly adjusting the number of turns in the series winding, the voltage at the terminals of the machine is made practically independent of the load. This additional series winding is called the compounding winding, and the dynamo is said to be compound-wound.

By providing more turns in the series winding than is necessary to compensate for the voltage drop, the machine is over compounded , in other words, the voltage rises with the load. In this case the dynamo is over compounded 25% as shown by the curme. Figure9.

Data for voltage characteristic of an over compounded generator.

Field amps.	Load amps.	Volts	Speed
.84	0	110	1450
.86	10	114	"
.92	20	125	"
.95	30	129	"
.98	40	133	"
.99	50	134	"
1 .01	60	136	"
1 .o2	70	138	"
1 .02	80	138	"
1 .02	90	137	"
1 .02	100	136.5	"

The curve is shown in figure 9.

As already mentioned a direct current machine can be operated either as a generator or as a motor. In the former case it transforms the mechanical energy of the prime mover into electrical energy available at its terminals; in the second case it converts the electrical energy input from the line into mechanical energy available on its shaft. In both cases this transformation

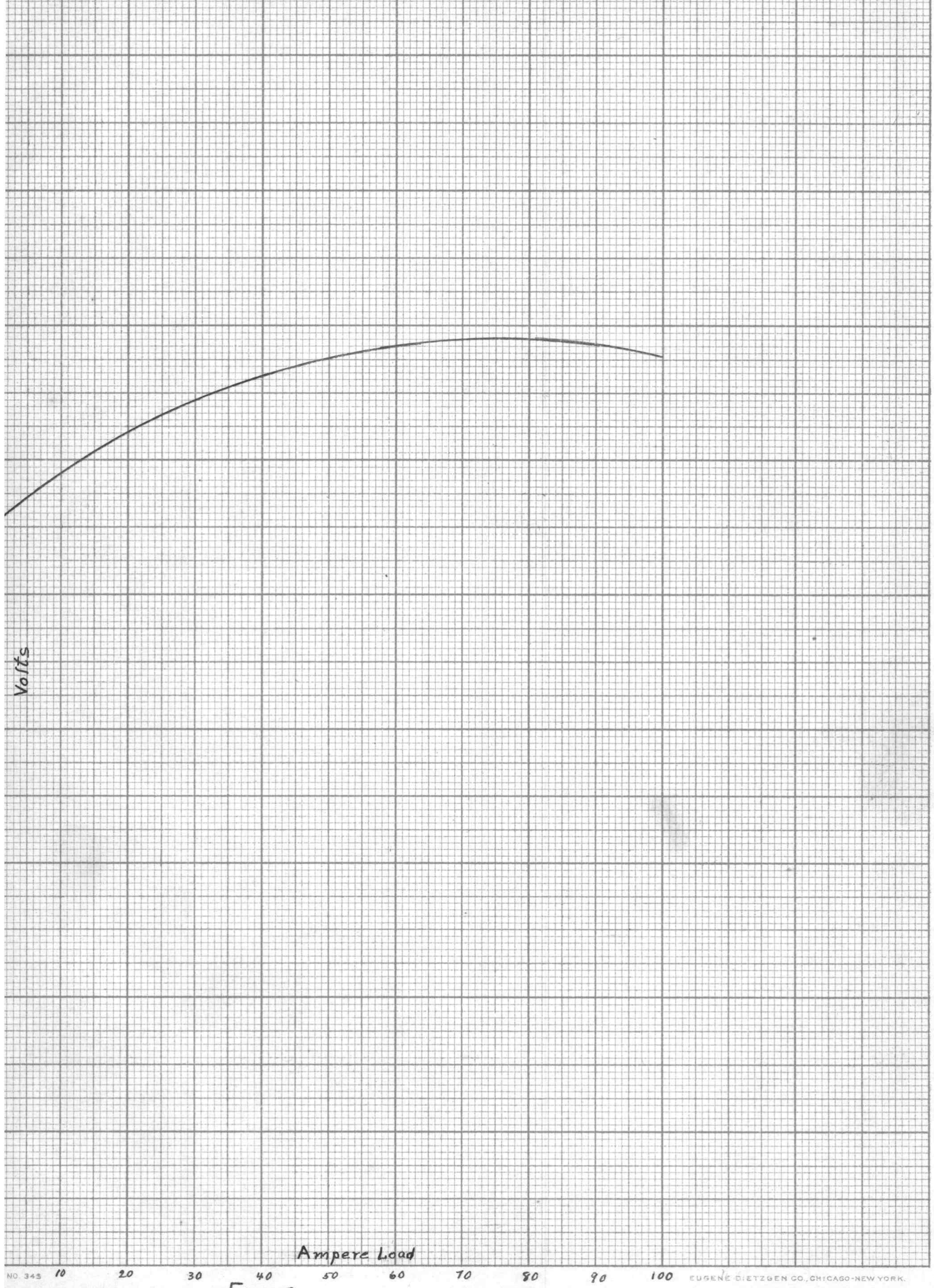
Volts
Ampere Load
10
20
30
40
50
60
70
80
90
100
NO. 345
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Fig. 9

of energy is necessarily accompanied by losses in the machine itself.

These losses cause the output of the machine to be less than the input and the ratio of the two is called the efficiency of the machine. That is:
Efficiency of a motor equals electrical input munus losses divided by electrical input.

This expression applies to the indirect method of determining efficiency although it is identical, in principle to the formula applying to the direct method. Both mithods are used in practice, and there are cases in which each one is preferable. In the present case the indirect method is used on account of greater accuracy and because, by this method the segregation of the losses into the separate components is made possible while by the direct method only the sum total of the losses can be obtained.

The procedure is in brief, to run the machine under test at no-load and to determine the power necessary for driving it. The power is used, in this case entirely for over coming the losses and is thus a direct measure of the total losses.

The losses in an electrical machine whether running as a motor or as a generator, can be sub- divided into three different classes: 1st. copper losses (I^2R) in the armature and in the field-circuit. 2nd. Iron losses(hysteresis and eddy currents) in the armature core. 3rd. Mechanical losses: bearing friction, brush friction and windage(air resistance).

The copper losses need not be determined experimentally ; it is only necessary to measure the ohmic resistance of the corresponding windings; ~~the~~ the I^2R loss can be calculated for any desired value of the current.

The iron loss in any machine depends upon the magnetic flux of the machine and upon its speed. On shunt wound machines the flux is constant as long as the field current is constant. The speed is also approximately the same at all loads; Therefore, the iron loss under these conditions is nearly constant.

The brush friction and the windage loss depend on speed only. The bearing friction is constant in a direct connected motor but when it is used for belt drive the friction depends on the tension of the belt, but this increase in friction could hardly be taken into account and it is costumery not to charge it to the motor.

Therefore the items; iron loss and friction in a shunt wound machine can be assumed nearly constant at all loads, and having the same value as at no load. This gives a convenient method for measuring these losses; all that is necessary is to measure the amount of power put into the armature, running at no load. This input is all converted into iron loss and friction with the exceptionof a small part which is necessary for supplying the I^2R loss in the armature winding and in the brushes. This correction is usually negligible, but if necessary can be readily calculated.

The efficiency was calculated as follows: It was found at no load the motor takes twelve amperes (armature current), and the field current at which the motor run was 0.95 amperes. The resistance of the armature was found to be .0067 ohm. The no-load losses(neglecting copper loss) consisting of iron loss and friction loss equals 110 x 12 equals 1.320 kilowatts; excitation loss equals 110 x .95 equals .104 kilowatts; total losses independent of the load equals 1.32 plus.104 equals 1.424 kilowatts. The copper loss in the armature depends upon the load.

The whole efficiency curve is constructed from no load to one and half loads. An ideal nine killowatt motor takes at full load, 9000 divided by 110 equals 82 ampers. We constructed the efficiency curve for points between 20.8 ampersto 123 ampers. Take for instance, 82 ampere point. Total electrical input equals(82 plus .95) x 110 equals 7528.4 watts; copper loss in the armature equals $(82)^2$ x.0067 equals 51.6 watts; total loss equals 1425 plus 51.6 equals 1471.6 watts.

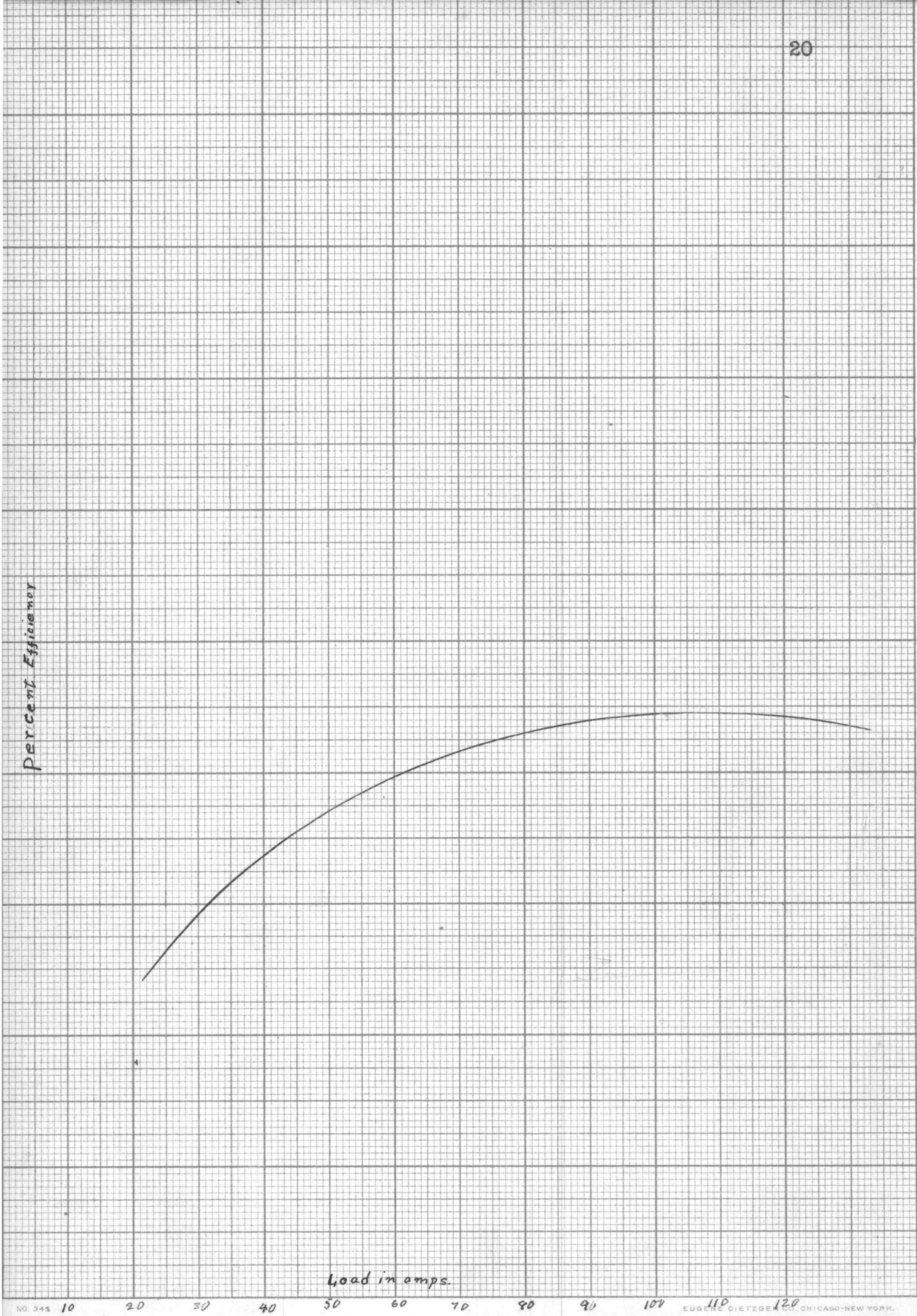
Percent Efficiency
Load in amps.
NO. 345
10
20
30
40
50
60
70
80
90
100
110
120
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Fig. 10

The efficiency is 7528.4 minus 1471.6 divided by 75284 equals 83.6 %. In this way the various efficiencies are tabulated at the different parts of load.

Data for efficiency. Resistance of armature without brushes is .0067

Proportion. load.	load in amps.	I^2R loss watts	iron loss watts	total loss watts	input watts
$\frac{1}{4}$	20.8	2.8	1425	1427.8	822.2
$\frac{1}{2}$	41	11.25	"	1436	3074
1	82	51.6	"	1471.6	7528.4
$1\frac{1}{4}$	102.5	70.28	"	1495	9755
$1\frac{1}{2}$	123	101.8	"	1526.8	11983

output watts	efficiency percent
2250	36.4
4510	68.5
9000	83.6
11250	88.5
13510	88.

The curve is shown in figure 10.

The armature resistance without brushes is .0067 ohms; with brushes is .1 ohm. The resistance of the field was found to be 2.74 ohms.

The machine upon which the foregoing tests were run was doing duty in the old Mechanical Hall when that building burned in 1898.

The insulation burned, but the yoke and base suffered no serious deformation. It was taken from the debris and worked over and in so doing a liberal amount of copper was allowed, as were also other requirements for good operation. As a result the machine is now giving service for experimental purposes in the Electrical Engineering laboratory and is fairly efficient, in fact, it is in general more efficient than is shown by the tests owing to the fact that some of the conditions were, (unavoidable) not ideal.