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REGULATION TEST OF A THREE WIRE D. C. GENERATOR

for the Degree of

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

by

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REGULATION TEST OF A THREE WIRE GENERATOR.

Theory and principles of operation.

A three wire generator, as the name implies, is a generator with three terminals, between any two of which the load may be applied. Two of the terminals come from the brushes as in an ordinary two wire d. c. machine. The third terminal comes from the middle of the armature.

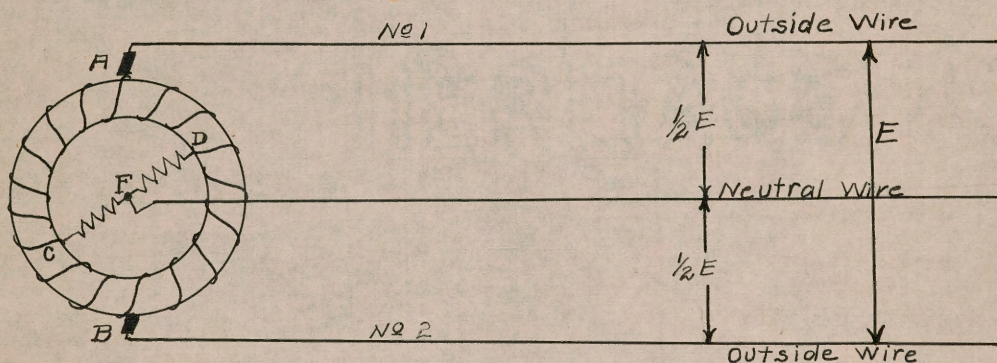


Fig. 1.

In the above sketch are shown the elementary features of a three wire generator. The neutral wire is connected to the middle of a coil which is connected to two diametrically opposite points on the armature. In actual practice this balance coil, as it is called, is not in the armature as shown, but may be put in any convenient place and connections made to it by means of collector rings and brushes. However for the sake of simplicity it will be discussed as shown, for the present.

In Fig. 1, A and B represent the direct current brushes of the generator. The balance coil is symmetrically connected to the

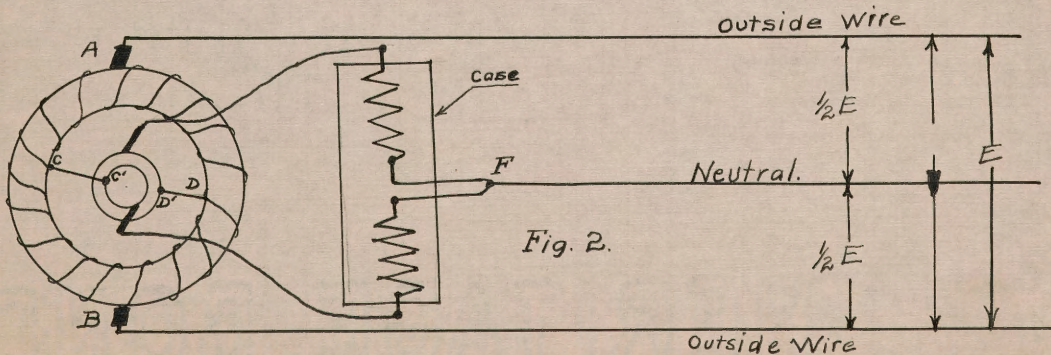
armature winding at points C and D. The neutral wire connects at F, the middle point of the coil.

Since the windings and connections are symmetrical, it is evident that when the terminals of the balance coil are directly under the brushes, the balance coil is subjected to the full voltage of the generator.

Between F and A the voltage is equal to that between F and B, and is equal to $1/2$ that between A and B. Correspondingly when the armature has rotated 90 degrees, the balance coil is subjected to no voltage, so that the voltage between F and A, and F and B are equal respectively to the voltages between D and A and C and E. But as the windings are symmetrical, the voltage between D and A is equal to that between C and B; consequently the voltages are equal between F and A and F and B.

In any other position of the armature the voltage between F and A is the resultant of half the voltage of the balance coil and that of the armature winding between A and D. It follows that the voltage between F and B is the resultant of those between C and F and C and B. But as the voltages of AD and BC are always equal and the voltage DD is always equal to EC, the voltage FA must always be equal to FB and is therefore the neutral point.

Thus we have one generator from which two voltages are available, which is often very convenient.



In Fig. 2 is shown the method of connecting the balance coil. The points C and D of the armature are connected to the collector rings, C' and D' which are mounted on the shaft with the armature. To the brushes of these collector rings, the balance coil is connected. This coil is usually placed in an iron case like a transformer and mounted on the wall or in some other convenient place, and leads from the collector rings brought to it.

When all the load is applied between the outside wires the action is exactly like an ordinary two wire machine, and the balance coil is not necessary to the operation at all.

Suppose all the load to be applied between the neutral and one of the outside wires. Then since one outside wire is not connected to the load at all, the current in the other outside wire must return through the neutral. From the neutral wire it flows through the choke coil back to the armature.

When the two sides are both loaded, but unequally, it is evident that the difference of the currents in the outside wires will return along the neutral.

When the two sides are loaded equally, no current flows in the neutral for it is the same as if a load were applied between the outside terminals only.

It follows that the balance coil must be made so that it offers the least possible resistance to the direct current which returns through it, and the greatest resistance to the alternating current, for it is constantly subjected to an alternating voltage equal to the generator voltage divided by the square root of 2 and the smaller the alternating current which passes through it, the better. Accordingly the coil consists of rather heavy wire wrapped around a laminated iron core, so that it has a

high inductance.

It is evident that the only purpose of the balance coil is to prevent a short-circuit between the points C and D of the armature. If it were not for short-circuiting the machine, a large wire would do just as well as the coil.

DESCRIPTION OF THE MACHINE AND CONDITIONS.

The generator under investigation is a 50 K. W. 6 pole 250 volt machine, direct-connected to an 80 H. P. American Ball Compound engine. The generator is rated 10% over-compounded.

The Load is made up of lights and motors. From 5:00 P. M. to 11:00 P. M. the load consists of lights only and under ordinary conditions the machine runs about half loaded during those hours. From 2:00 to 5:00 in the afternoon the load consists of motors and lights, the number of lights depending upon the season of the year. During the early part of the afternoon there is a comparatively light load upon the machine, and in the winter or when darkness comes early, the load runs up sharply about 4:00 due to the increased number of lights; sometimes going to 25% over-load, During the season when darkness comes late, the load seldom comes near full load at any time.

Three of the series fields are in one side of the circuit, and three in the other, so that there is a series field current when only one side is loaded. In all the discussion following, Side No. 1 of the machine is the circuit from the left switch bar to the middle bar on the main three pole switch on the switch-board, and Side No. 2 refers to the circuit from the right bar to the middle bar on the same switch. There is only one volt-meter upon the switch board and this one is connected across side No. 2 so that another volt-meter is necessary to measure the voltage of

No. 1. There is an ammeter on each side of the machine so that the total current may be measured. There are separate ammeters to each feeder line.

PREPARATION FOR THE TESTS.

The two main switch-board ammeters were calibrated by placing a shunt in series with the line and measuring the drop across it with a milli-voltmeter. The shunt was standardized so that when used with the proper milli-voltmeter, amperes were read directly. The results are shown on another page and indicate that ammeter No. 1 is slightly off but not enough to seriously effect the calculations. No. 2 is practically correct.

The voltmeter was compared with the laboratory standard and found to be correct within 1% at ordinary voltage.

THE CHOKE COIL. The choke coil is constantly subjected to an alternating voltage of about 172 volts. Hence there is always an current flowing in the coil in addition to any direct current, that may be present.

The d. c. resistance of the coil was determined by running a known direct current through it and measuring the voltage drop across it. The a. c. resistance, inductance, and watts lost in the coil were determined by voltmeter, ammeter and watt meter readings when an alternating current only was flowing.

Below are the data on the coil under ordinary conditions:

A. C. Voltage applied to coil	172 volts
A. C. Current in coil	3.0 amp
Watts lost	94
Cos. ϕ or power factor.. ..	0.182
A. C. Resistance	10.4 ohms
Inductance	56.3 "
D. C. Resistance	0.130 "

The choke coil is designed to carry the current at 25% unbalance or 50 amperes. After running 6 hours with an unbalance of 40 amperes the temperature of the oil in the coil was observed to be 120 degrees and the surrounding air was 82. Far.

The leads from the coil, the collector rings, and the taps from the armature winding to the collector rings did not show any perceptible rise in temperature. This indicates that the amount of unbalance is limited by the coil only.

In the passage of the direct current through the choke coil a rather complex action takes place. Referring to Fig 1, when the points C and D are 90 degrees from the d. c. brushes, that is when the coil is horizontal in the figure, the two sections of the coil are in parallel with respect to the direct current and the resistance at this instant is $1/4$ of .13 or .032 ohm. When the points C. and D are directly under the d. c. brushes the current in the neutral returns to the armature through only one of the sections of the coil. Thus the resistance at this instant is $1/2$ of .13 or .065 ohm. In intermediate positions part of the current passes through one section and part through the other .

Hence it appears that the total unbalanced current is flowing through first one section and then the other of the coil, going from 0 to full amount according to a sine law. But if this action does take place, it certainly seems that there would be a great resistance to the passage of the direct current for it would magnetize the coil first in one direction and then in the other, thus choking the current considerably. It seems that it would also cause a great deal more difference in voltage at unbalanced loads than it really does. It is not pretended in this test to explain this question. A possible solution is that the direct current

does not go from 0 to full amount in this manner but is always nearly the same in the two sections, fluctuating only a comparatively small amount. However this is only a matter of spectlation and is not guaranteed to be true. It would be interesting to make an oscillogram of this direct current. It is evident that the average resistance of the coil depends on the action of this current so it cannot be determined accurately. It is probably not far from $\frac{3}{8}$ of .13 ohm or .048 ohm.

REGULATION.

The chief object in this test is the investigation of the change in voltage of the two sides of the generator at various loads both balanced and unbalanced, but especially unbalanced loads. With unbalanced loads the voltage action is as in other respects, like that of an ordinary 2 wire machine. But with unbalanced loads this is not the case.

The usual lighting load consists of about 135 amperes on side No. 1 and about 95 on No. 2. With this state of affairs the voltage of No. 1 is about 6 volts lower than that of No. 2. Hence the consumers on No. 2 are getting better service than those on No. 1.

This fact then, causes an interest in the relation of the voltages with various other unbalanced loads, and whether they seem to follow any consistent order in their changes or not.

The investigation of these things is the chief object in this work. This was done by putting various loads on the machine and observing the voltage on each side. The load was made up of rheostats and the natural load: i. e. lights on the hill.

The natural load was used as far as possible, the rheostats being used only to bring the load to the desired value when the natural load would not do. In general, an unbalance of 50 amperes

was applied alternately to each side with different loads from zero to full load. Some readings were also taken with balanced loads.

There were two methods used as follows: a load was put on the generator and the voltage read on each side. The circuit breakers were then opened and the voltage on each side again read. The speed was also taken at load, and no load in order to make allowance for a change in speed if necessary.

In another method the voltage was set at some value at no load and then, without changing the field rheostat, various loads put on the two sides and the voltage read at each change in load.

These results are shown graphically on curve sheets and also on the log sheets. The data given here is not all that was made in the whole test. It is the data in the test which gave the most consistent results and may be said to be a fair representation of all the data and the behavior of the machine.

DISCUSSION OF RESULTS.

On the sheet marked No. 1 is shown the voltage action at balanced loads from no load to full load. The data for this curve was obtained by reading the voltage at some load and opening the circuit breakers and again reading the voltages. No effort was made to keep the no load voltage constant, as is shown by the curve. This curve shows a rise in voltage with an increase of load and reaches a maximum at about $3/4$ load after which the voltage decreases as the load increases.

It is interesting to note that as the load becomes greater, the voltages of the two sides, instead of remaining equal to each other as they theoretically should, begin to separate and at full load there is a difference of two volts. There was no convenient

way of determining the cause of ~~this~~. The resistance of the two series field shunts was measured and found to be the same, so it is probably due to a difference in resistance of the two circuits between the voltmeter and the generator.

On Curve No. 2 is shown the variation of voltages with the no load voltage constant. In finding these data, the voltage at no load was read and then various loads applied without changing the field rheostat, and the voltages read at each change in load.

These data show essentially the same characteristics as the other case. There is a difference of voltage of the two sides when loaded, and the same rise and fall of voltage with increasing loads. The lower curve is the voltages as read and the upper curve is the same with a correction made for a drop in speed at loads. In making this correction, the voltage was assumed to be proportional to the speed, which, while not strictly true, is near enough so for all practical purposes. Even with this correction there is a plainly defined drop in voltage at full load.

The maximum voltage seems to be at about $3/4$ load. The results all through the test seem to indicate that the rise of voltage with the load is greater when the no load voltage is small. That is, the greater the voltage the less the change in voltage with a change in load.

This seems to indicate that the drop in voltage, at full load, is caused by the saturation of the field magnet, at about $3/4$ load. At low voltage there is not so much field current in the shunt windings, and the voltage is therefore raised more by the series field current than when the shunt field current is larger.

UNBALANCED LOADS:- On curve No. 3 is shown the variation of voltage with different amounts of unbalance from 0 to 50 amperes. This data was obtained by reading both voltages at 0 load and applying a load to one side only, leaving the other side 0 and reading the voltages at each change of load. This was done for both sides. In each case the voltage of the loaded side decreased and the voltage of the unloaded side increased. At 50 amperes unbalance there was in each case a difference of voltage of the two sides of 7 volts.

This is caused partly by the resistance of the choke coil and the leads between the generator and the voltmeter. On the loaded side there would be a drop in voltage equal to RI where R is the resistance of this circuit and I is the current flowing through it. The unloaded side would evidently have no such drop since there is no current.

If the voltage of the loaded side decreases then, the voltage of the unloaded side will increase. If we call the resistance of the choke coil .048 the RI of the coil at 50 amperes unbalance is about 2.5 volts. Increasing the voltage of the other side by this amount, and we have accounted for a difference of voltage at 50 amperes unbalance, of 5 volts.

The resistance of the leads from the machine is small, being No. 00 wire. This resistance accounts for 0.3 volt drop. The remainder of the 7 volts drop is doubtless due to the choking action of the balance coil.

From these facts the conclusion may be drawn that the current is nearly constant in each of the two sections, fluctuating only enough to cause a drop in voltage of about 0.8 volt.

Curves No. 4 and No. 5 show the variation of voltage with a constane unbalance and ~~variable~~ load. In finding this data, the field rheostat ~~was~~ not changed so that the no load voltage remained constant. A test similar to this was also made except that the load voltage was kept nearer constant than the no load voltage. These results in general agreed with those shown on the curves so that they were not plotted.

These curves 4 and 5 are similar to the balanced load curves in the respect that the voltage first rises and then falls as the load increases uniformly. They also show one important fact which is conspicuous throughout the whole test, viz; that with constant unbalance the voltage difference is constant at all loads. In other words, the difference of voltage depends upon the mount of unbalance only.

CONCLUSION.

The most important and useful facts brought out by this test are as follows:

1. At balanced loads there is a slight difference of voltage of the two sides but not over two volts.
2. The rise of voltage at full load is less than that at $3/4$ load even if the generator were run at constant speed. Under actual conditions, the full load voltage is only two or three volts higher than the no load voltage.
3. The difference of the two voltages is dependent only upon the amount of unbalance.

Calibration of switchboard Ammeters.

Ammeter No 1	Millivoltmeter No 7864	Ammeter No 2	Millivoltmeter No 7864.
138.	138.0	130.	133.
130.	130.0	125.	128.
115.	115.0	112	114.
110.	110.0	102	104.
105.	105.0	94	96.
100	100.0	88	90.
72	71.5	83	85
65	64.0	81	82.5
61	60.0	45	46
45	44.0	29	29
19	18.0	15	15
12	11.0	6	6

Ammeter No 1 = No 57857 on switchboard

" No 2 = No 57856 " "

Voltage characteristic at balanced loads.

with field rheostat adjustment.

Amps. No 1	AMPS No 2	Volts No 1	Volts No 2	speed r. p. m.	Volts No 1 corrected for speed	Volts No 2 corrected for speed
25	26	120	120	285		
0	0	118	118	285		
53	52	121	122	284		
0	0	118	118	285		
76	74	121	122	284		
0	0	118	118	285		
105	105	123	124	282		
0	0	118	118	285		
154	155	116	118	282		
0	0	106	106	287		
200	201	113	116	281		
0	0	106	106	287		

Without field rheostat adjustment.

0	0	118	118	286	118	118
25	25	120	120	286	120	120
50	50	122	122	285	122.5	122.5
75	75	123	124	285	123.5	124.5
105	105	124	125	283	124.8	125.8
125	125	123	125	283	124	126.
153	153	122	124	282	124	126
200	200	117	120	277	121	124

Unbalanced Loads. variable unbalance

zero load Voltage Constant.

Amps No 1	Amps No 2	Volts No 1	Volts No 2
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0	0	122	122
0	13	123	121
0	15	123	121
0	19	123.2	120.4
0	25	123.5	120.
0	40	124.8	119.7
0	57	126.	119.3
0	0	122.	122

0	0	122	122
13	0	120	123
15	0	120	123
18	0	119.2	123.5
25	0	118.	124
38	0	118.	124
47	0	118.	125
55	0	117.	125.5

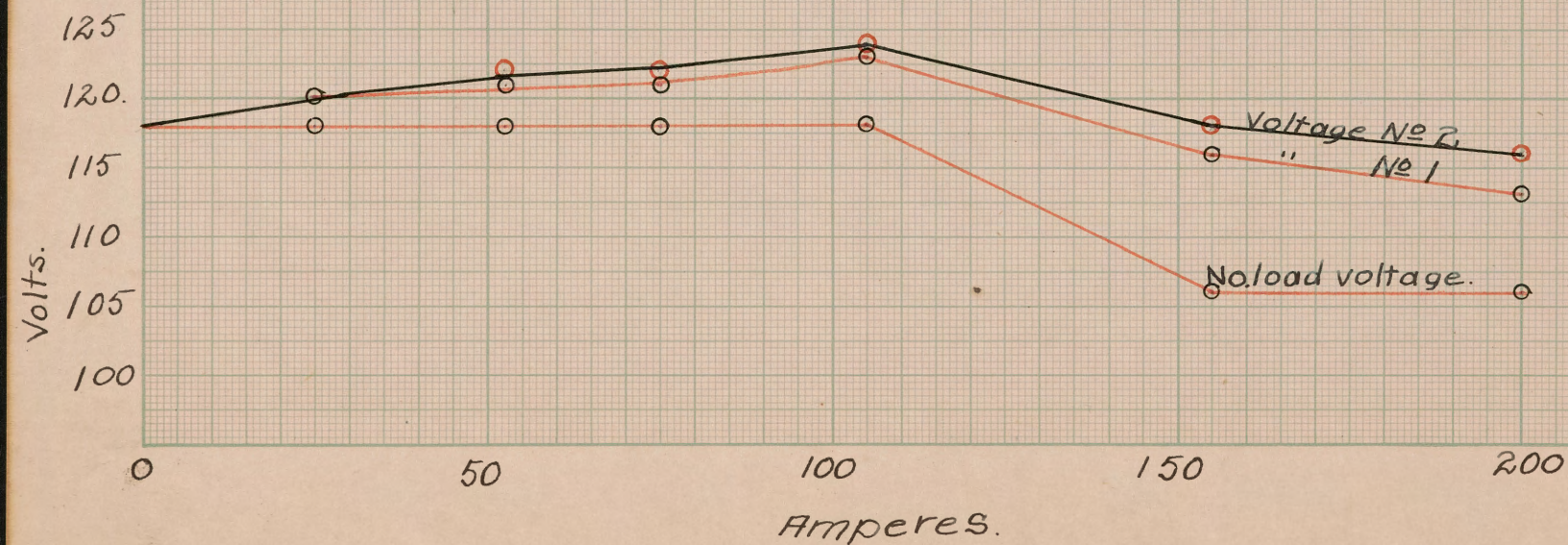
Unbalanced Loads.

CONSTANT UNBALANCE

Zero Load Voltage constant.

AMPS No 1	AMPS No 2	Volts No 1	Volts No 2	speed r.p.m
0	0	116	116	286
0	25	118	115	286
25	0	115	118	286
0	52	121	114	284
50	0	118	120	284
52	102	125	118	283
104	53	119	126	283
150	100	121	128	282
100	150	127	120	281
150	200	122	116	280
200	150	115	123	279

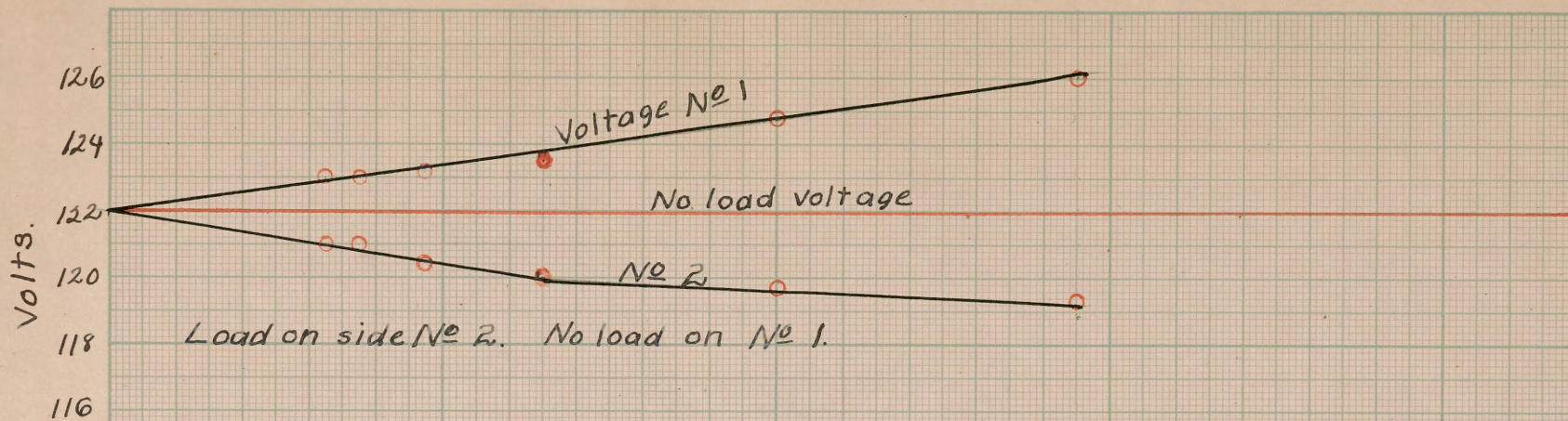
CURVE NO 1
Balanced Loads.





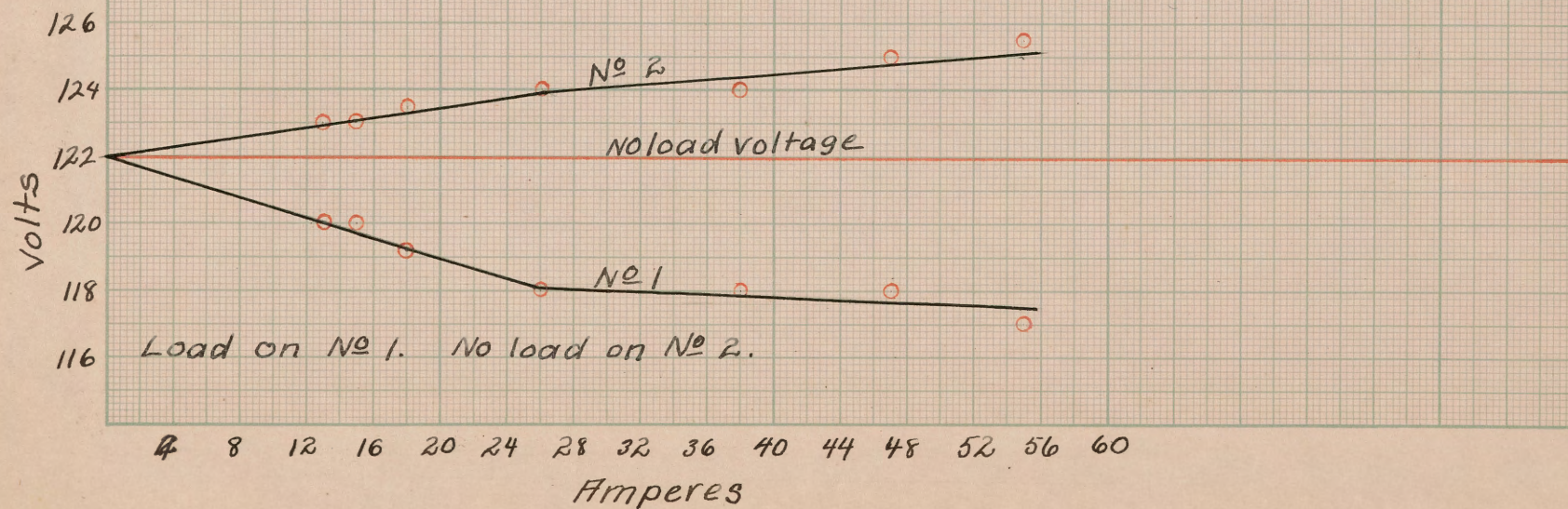
CURVE NO 2.
Balanced Loads





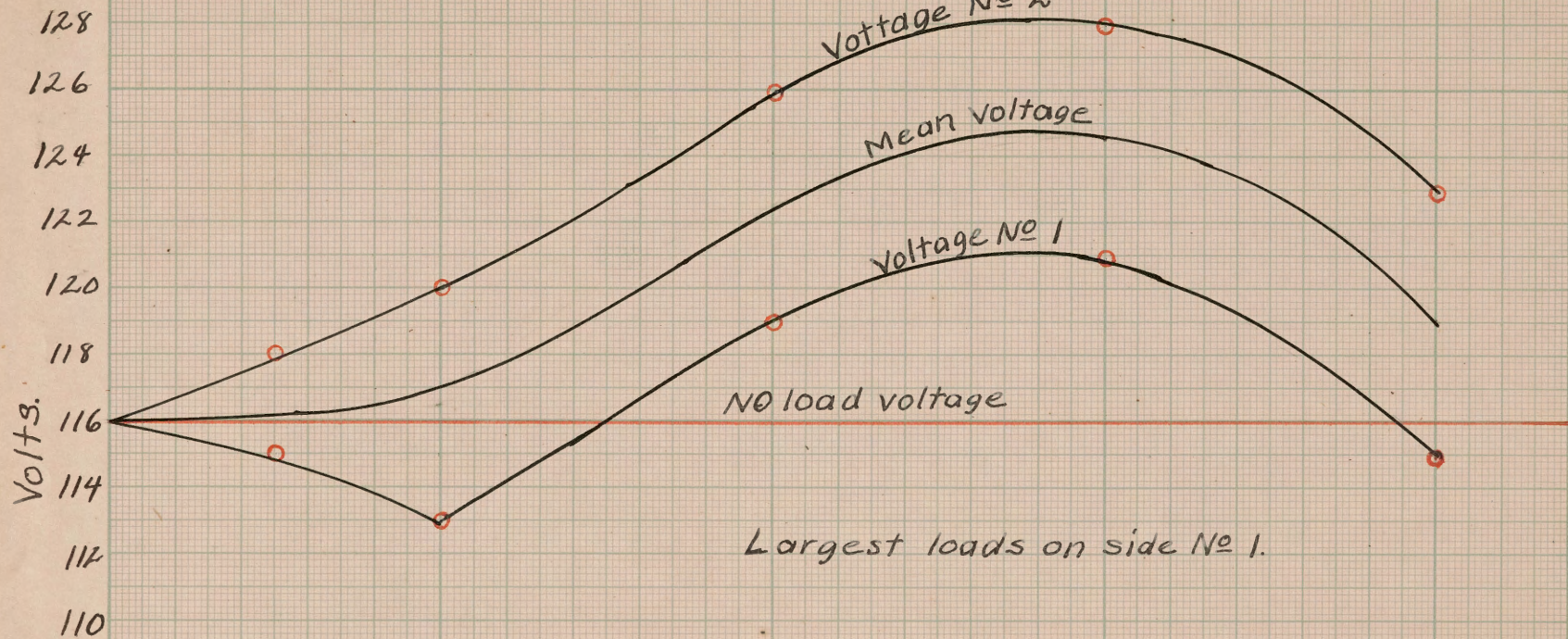
CURVE NO 3.

Unbalanced Loads.



CURVE NO 4

Unbalanced Loads

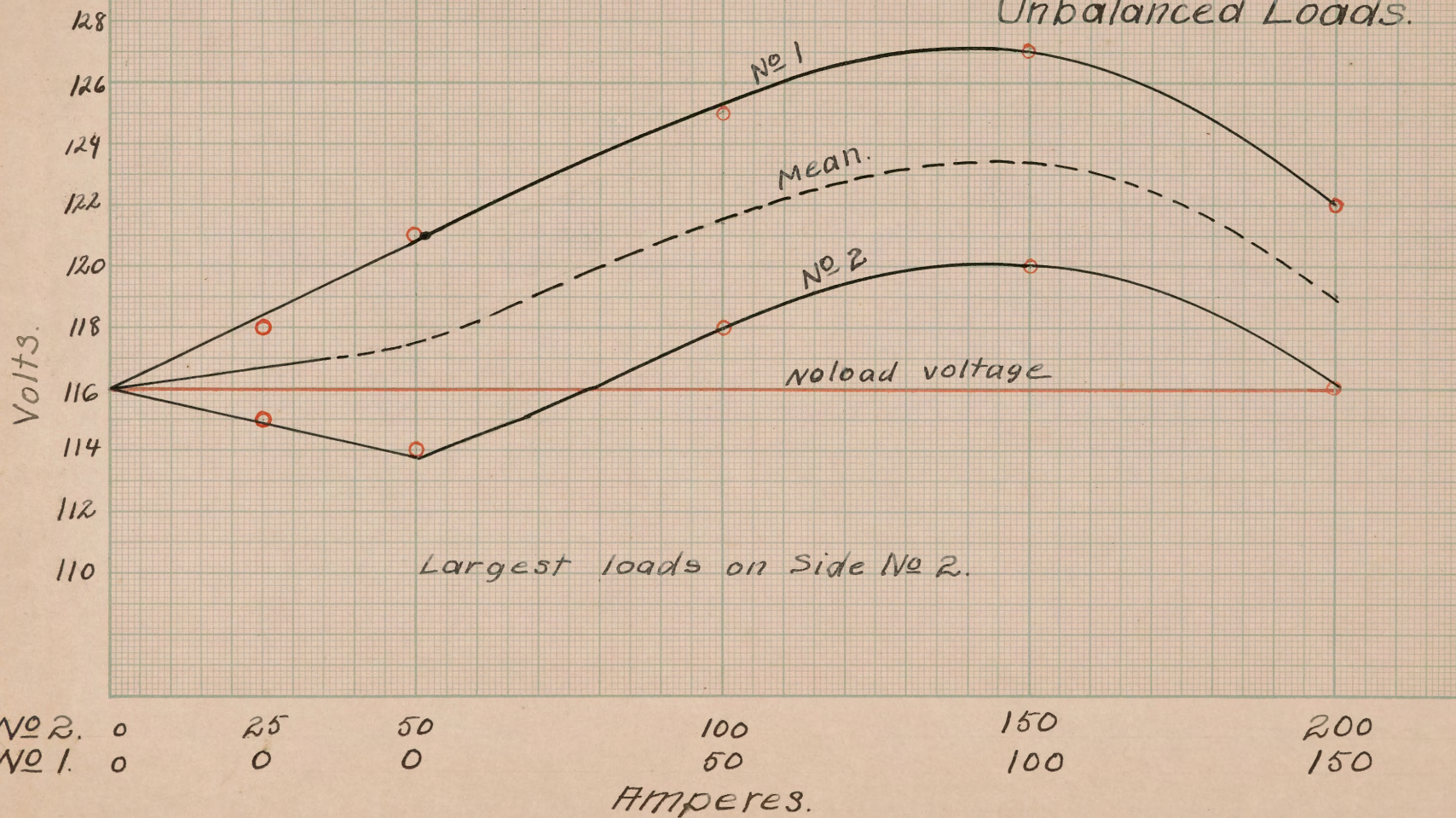


No 1.	0	25	50	100	150	200
No 2.	0	0	0	50	100	150

Ampres.

CURVE No 5

Unbalanced Loads.



No 2.	0	25	50	100	150	200
No 1.	0	0	0	50	100	150