THE TIRRELL REGULATOR.

by

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THE TIRRELL REGULATOR.

The voltage regulation of electrical generators has always been a very important problem, and one that has been very difficult to solve. Formerly when the field was held by shunt generators the suppy depended entirely upon a switch board attendentwho endeavered to keep the voltage as nearly as possible to the desired point; by shifting the rheostat arm when the voltmeter showed a fluctuation in the voltage. While this method was satisfactory for average pressures it was not satisfactory with a rapidly changing load.

An observant attendant could be depended upon to bring the voltage back to normal as soon as the voltmeter showed that a change had occured. But this required appreciable time, during which the voltage continued to rise or fall as the case might be, before the normal pressure could be restored, it was impossible to maintain a constant voltage. This fact alone was of sufficient importance to give an incentive to inventors to try to discover a more satisfactory means of regulation. Some automatic method seemed to be the most feasable, and from experiments along this line came the ideas that were afterward applied to the developement of the compound generator, which is to a certain extent self regulating. However the compound machines are far from being self regulating, since the magnetization is not directly proportional to the magnetizing current.

The same general method of developement was followed in the alternating current generators. When they first came into use a switch board attendant was relied upon to keep the voltage constantby making such changes as the voltmeter or potential indicator showed were necessary. Some time later the principle of the compound generator was applied to the compound or compensating alternator. The greatest difficulty in applying this principle was that of self induction. With the discovery of methods of rectifying current this difficulty was largely overcome. The main objection to rectifier is that they add to the complexity of the dynamo and cause considerable trouble because of their delicate mechanism. The voltage control is not perfect for the same reason that it is not perfect in the direct current generators.

A mechanism has been recently invented which offers a more successful solution to the problem of voltage regulation. It is an automatic device placed outside the machine. Instead of acting upon the alternator voltage it acts directly upon the exciter voltage. The compounding current is small since the alternator is worked on that part of the magnetization curve where a slight change in current, in the alternator field, will result in an appreciable change in the voltage. By varying the field of the exciter its output and and therefore the field of the alternator is varied. It may appear as if this method is no better than those formerly employed as it also provides a means for varying the alternator field.

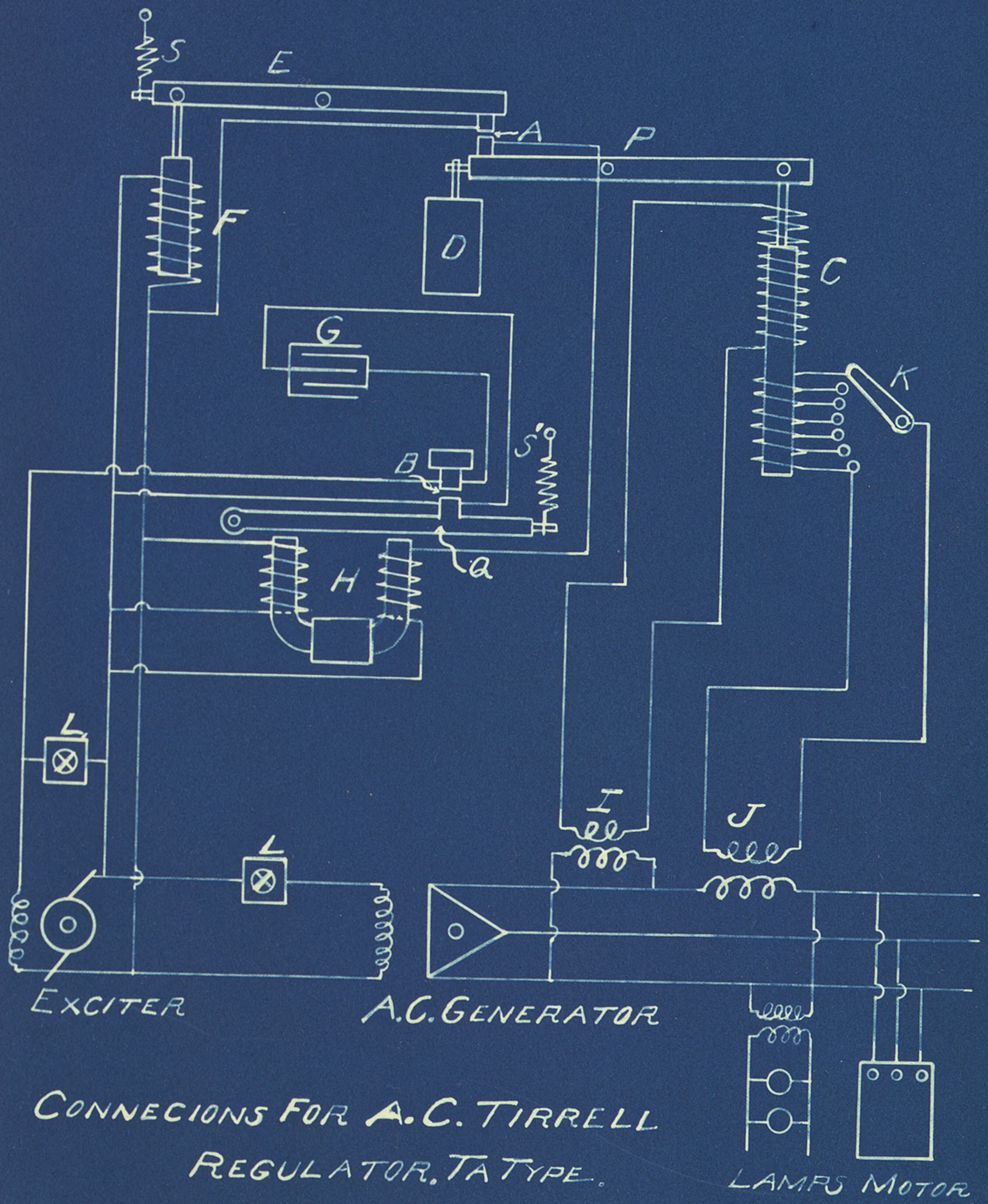
Mr. Tirrell developed the idea that if the exciter be designed to respond quickly to a change in its field excitation the voltage of the alternator could be held constant by repeatedly short circuiting a portion of the exciter field resistance

The success of the mechanism depends upon this principle. His scheme was to regulate the duration of each short circuit by a system of electro-magnets, which when properly set to give a certain voltage over the alternator mains, would retain that voltage for a large range of load. The moving parts of the Tirrell regulator are very sensitive to change of pressure and move with great rapidity. The details of the regulator and its effect upon the voltage will be given in the following pages.

The voltage of the alternating current generator is automatically maintained at any desired pressure by varying the exciter voltage by means of the regulator. This is accomplished, not by varying the amount of resistance in the circuit, but by repeatedly short circuiting a fixed resistance. The exciter field rheostat is the resistance that is shunted. The duration of each short circuit being varied automatically. The principle employed here is that the actual resistance varies as the duration(duration)of the short circuited rheostat provided that the rheostat is short circuited repeatedly during short intervals of time.

The illustration on diagram sheet #1 shows the elementary connections of the Tirrell regulator. The rheostat shunt circuit is opened and closed by the differential relay (H). The current for operating the relay magnet is taken from the exciter bus bars and is controled by the floating contact (B). The current that operates the direct current magnet (F) is also taken from the bus bars. The alternating current portion of the regulator consists of a magnet (C) having two windings. One is a potential winding connected by means of

#1



CONNECIONS FOR A.C. TIRRELL
REGULATOR. TA TYPE.

a potential transformer to the circuit to be regulated. When the voltage is 110 as in this case the regulator is connected directly with out a transformer. The other is an adjustable compensating winding, which is connected in series with the secondary of a current transformer(J) which is placed in the phase carrying both a power and a lighting load. The core of the alternating current magnet is attached to one end of a lever pivoted at (P). Suspended from the other end of the lever is a counter balance (D). The weight of the alternating ing current magnet core is greater than that of the counter balance, and when the pressure drops in the potential windings of the magnet contact is made at (A) since the action of the potential winding is to raise the core. The core is provided on its lever end with a piston working in a dash pot filled with oil and which acts as a damper when the load fluctuates. If a load is thrown on the generator the voltage tends to decrease. The potential transformer (I) connected over the mainsthen has a decreased voltage impressed over its primary and the secondary voltage is also decreased; hence the current in the secondary which flows through the alternating current magnet. This magnet is then weakened and the balance between the counter weight and the core is destroyed, thus completing the circuit from the bus bars of the exciter through one leg of the relay (H). The other leg of the relay is permanently connected to the bus bars of the exciter. As the windings of the legs are directly opposite, the iron armature is no longer attracted by the relay (H) for its magnetism has been weakenedby closing the contact (A). The armature (Q) being released responds to the coil (coil) spring (S) and contact is made at (B) which entirely short circuits the exciter rheostat(L), causing a sudden rush of current through the exciter field which boosts up its voltage and sends a larger current through the alternator field. This in turn increases the generator voltage until the original balance between the alternating current magnet core and the counter weight is restored and the terminal voltage is brought up to normal. When the exciter voltage is increased thecurrent in the direct current control magnet winding (F) is increased and the lever (E), pivoted at at its center, is movedso that contact is made at (A) is opened. The rapidity with which the resistance is cut in and out of circuit depends upon the voltage maintained over the solenoid (F). The action of this magnet is more sensetive than that of the alternating current magnet because its potential comes directly from the bus bars.

The operation of the regulator at no load is due to the fact, that the amount of resistance shorted in the exciter fieldis such that when it is all in, the current in the alternator field will be of such magnitude as to give about 40 volts over the alternator terminals, and when entirely short circuitedwill give a voltage some what above normal. The action is similiar to that which takes place when the alternator is loaded. The only difference being that the action is faster, being actuated entirely by the direct current magnet.

The condensor (G) is placed in parallel with the relay contacts for the purpose of eliminating the sparking , due to self induction, that would otherwise occur when the field was broken. The sparking of this contact depends upon the field discharge of the windings and where an exceptionally large exciter is used it may be necessary to connect two condensors in parallel to keep down the sparking.

As the regulation of the alternating current generator depends primarily upon short circuiting of the exciter field resistance it is of importance that the proper adjustment be made in the exciter rheostat. The voltage impressed over the field of the exciter should be about 70 volts at no load. Then the alternator fieldrheostat is turned in or out as the case may be to give the desired voltage over the alternator terminals. After the alternator field rheostat has been adjusted the exciter field rheostat should be turned in to a point that will give about 40 volts over the alternator terminals. In other words the alternator voltage should be reduced from 40% to 60% below normal. After this point has once been determined on the rheostat it should be marked so the same amount of resistance can always be turned in when the exciter is cut in.

The machines usedas exciters are of special design and are worked at a point on the saturation curve which is considerably below the saturation point, there by allowing a large range of voltage for a comparatively small change in the field excitation. This assures quick action of the exciter when the regulator is in operation.

The counter balance is a small iron cylindrical cup in which small shot can be placed in order to obtain the proper relation between the counter balance and the alternating current magnet, for the desired voltage. This is very important and should be carefully adjusted. The acting moment of the counter balance is in the same direction as that of the

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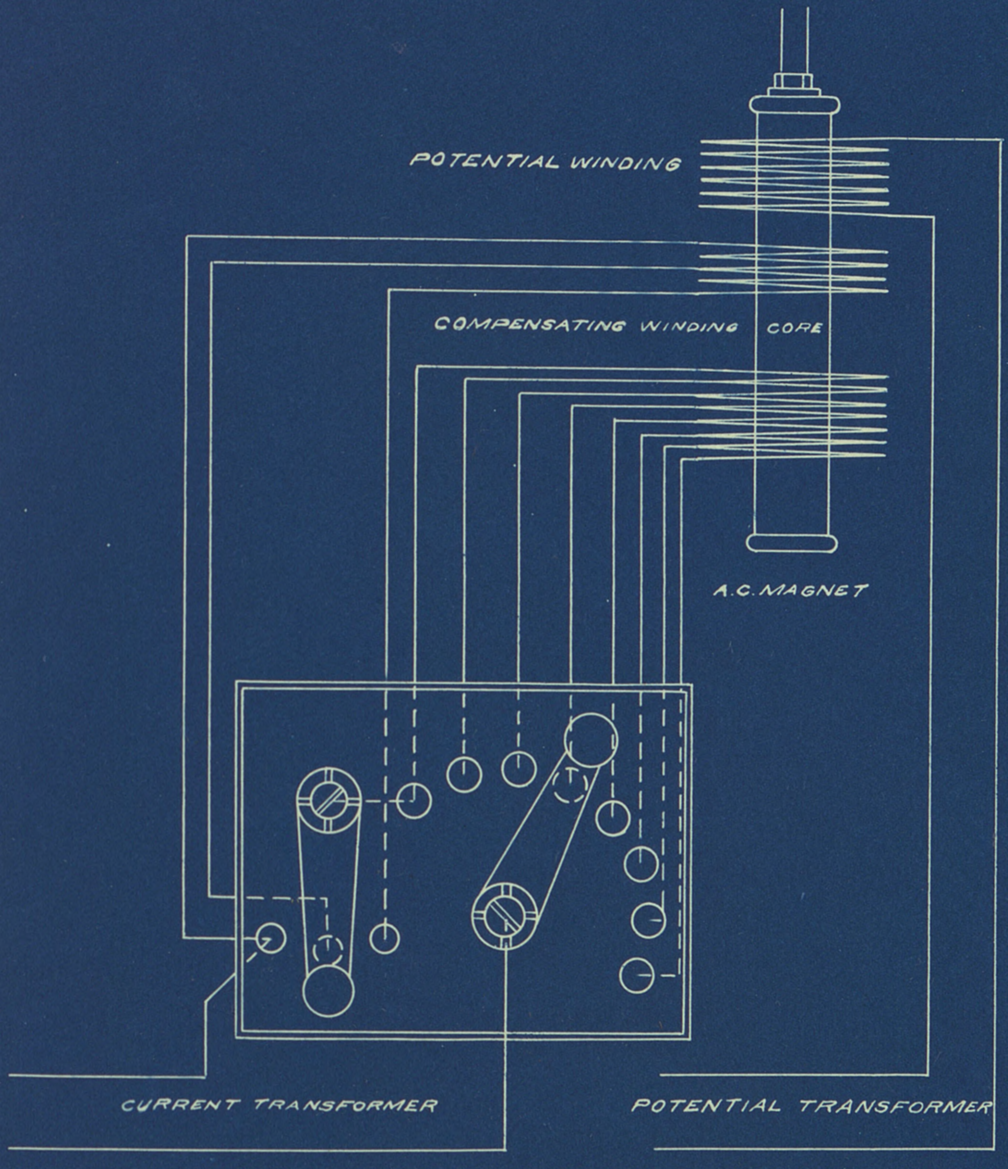
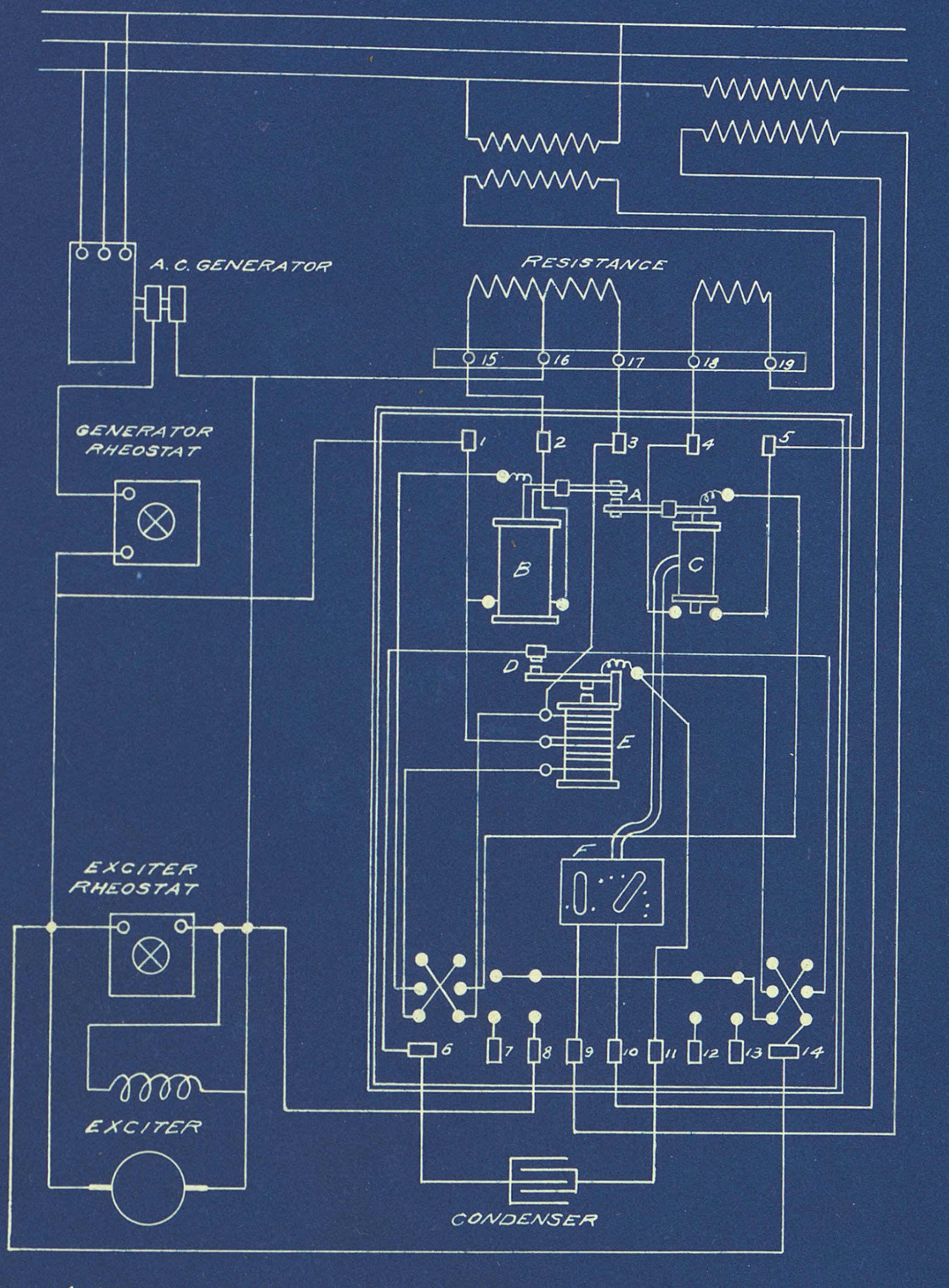
potential windings of the A.C. magnet. Therefore the effect of increasing the weight of the counter balance would be the same as increasing the ampere turns of the potential windings. In the first test run considerable adjustment was necessary. After the proper relations were secured between the field of the exciter and the alternator, the regulator regulated for too high a voltage. By gradually increasing the weight in the counter weight the voltage dropped gradually until the proper voltage was reached and then the counter weight could be left at just this weight. Increasing the weight of the counter balance, decreased the difference of moment between the magnet core and the counter balanceand resulted in a slower movement of lever (P) and a longer time interval occurs between the short circuits. This is the cause of the voltage dropping.

Good voltage regulation is one of the essentials of electric lighting. This is especially truewhere the lamps used are of the incandescent or mercury vapor types. The constant voltage which the Tirrell regulator gives insures (1) longer life to lamps, (2) it satisfies customers, (3)reduces lamp renewels, An increase of one percent above normal voltage reduces the life of a lamp 20% but with an increase in candle power of 6% while if the voltage is increased 6 percent the life of the lamp would be decreased 70 percent with an increase in candle power of but 40 percent. This shows clearly the advantage of keeping the voltage constant.

The object of the compensating adjustable winding of the A.C. control magnet, is to compensate for line drop so the compounding of the machine will give the proper voltage out on the line as the load is changed. These windings act in opposition


POTENTIAL WINDING
COMPENSATING WINDING
CORE
A.C. MAGNET
CURRENT TRANSFORMER
POTENTIAL TRANSFORMER



A. MAIN CONTACTS B. D. C. MAGNET C. A. C. MAGNET
D RELAY CONTACTS E. RELAY MAGNETS F. FOR ADJUSTING COMPENSATING WINDING.

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to those of the potential windings and give the same effect, as has been given before, of weakening the effect of the potential windings. The amount of compounding is adjusted by the two movable arms shown in the detailed drawing on sheet #2 Arm (A) makes contact with three lugs while arm (B) is able to make contact with eight. Data shows that the compounding effect of the eight lugs is the same as one lug of the other set. It can be seen that when the arms (A) and (B) are on their respective lugs in the first position the windings are entirely cut out. Curve sheet #1 shows curves plotted to volts and lugs. In curve (A) the load was constant at 40 amperes and the voltmeter was read for each successive lug. The slope of this curve shows that poor voltmeter readings were taken as can be seen by comparing with curve (B) which is more nearly correct and was taken in the same manner, excepting that a load of 50 amperes was used. Curve (B) rises above (A) because of the greater load which acts on the compensating windings.

Diagram sheet #3 shows a diagram of the connections of the Tirrel regulator as actually madeand the connections are numbered as on the apparatus.

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Data:-----------

Compounding value of the steps in the adjustable compensating series windings.

Load 40 amperes.

Volts	Lugs	
110	1	
112	1	
113	2	
115	3	
116	4	
117	5	
117.8	6	
118	7	
118		Large step #1.
118.5	1	
119	2	
119.5	3	
120	4	
120.5	5	
121	6	
122	7	
121.5		Large step #2.
121.5	1	
122	2	
123	3	
124	4	
125	5	
126	7	
127	7	

Data :------Continued.

Load 50 amperes.

Volts	Lugs	
109	0	
110	1	
111	2	
112.5	3	
114	4	
115	5	
116	6	
117	7	
117		Large step #1
118	1	
119	2	
120	3	
122	4	
124	5	
126	6	
125	7	
124		Large step #2
125	1	
126	2	
127	3	
128	4	
129.5	5	
130.5	6	
132	7	

1935

Data:----Continued.

Variation of voltage with speed when using the regulator.

Load 35 amperes.

Speed	Volts.
1240	110
1220	110
1200	110
1180	110
1160	109
1140	108.5
1120	108

Voltage regulation with a non-inductive load in one phase in which the current transformer was placed.

Flat compounded. Speed constant at 1200.

Amperes	Volts
0	110
10	110
20	110
30	110
35	110
40	110
45	110
50	110
55	110
62	110
65	110
68	110

1936

Data:-------Continued.

Non inductive load. Speed 1200 R.P.M.

Slightly over compounded.

Amperes	Volts
0	110
10	110.2
15	110.25
20	110.3
25	110.5
30	110.7
35	110.7
40	110.8
45	111
50	111
55	112.1
60	111.5
70	111.5

Over compounded for 125 volts at 65 amperes.

0	110
10	112.5
15	113.8
20	114.8
25	116
30	117
35	118
40	119.5
45	120.5
50	122
55	123

1937

Data:-----Continued.

60	124
64	125
65	125
68	126
69	126

Inductive load

Load:- Wagner single phase motor.

Amperes	Volts	Kilowatts.
0	110	0
12	k	.6
16		1
18		1.25
20		1.5
22		1.75
25		1.85
26		2
29		2.25
30		2.45

Load:-G.E.Rotary Converter as a synchronous motor and 3-phase induction motor.

Amperes	Volts	Kilowatts.
35	112	6.4
36	111	7.5
40	110	8.4
42	k	9.2
45		9.5
52		8

Data:- Continued.

54	k	8.5
56		9
62		9.5
67		12.95
22	110	4.3
30	k	6.4
36		9.2
40		9.3
50		9.5
54		10
55		10.4
58		10.5
60		11.2
62		11.5
63.5		12
64		12.4
68		13
72		14.4
74		14.5

The following test was taken to show the effect of the regulator upon the voltage when compared with the voltage regulation without the regulator . The load was changed through a number of values and the corresponding voltage read, the speed also being allowed to **fluctuate** in the latter part of the test.

Data:-----Continued.

With out regulator.

Time	Speed	Voltage	Watts	Output
8	1200	110	1.75	2.
8:5	k	121	.8	2.
8:10		125	.25	1.4
8:15		90	2.9	3.25
8:20		68	3.	3.1
8:25		90	2.15	3.1
8:30		111	1.25	4.3
8:35		110	1.75	3.
8:40		117	1.1	.8
8:45		125	.5	.5
8:50		95	2.	4.8
8:55		78	2.	5.2
9:		78	3.5	5.5
9:10		118	1.	3.75
9:15		90	2.75	2.25
9:20		84	4.25	5.
9:20		79	2.	5.25
9:25		60	3.	2.8
9:30		70	4.2	3.2
9:35		105	2.5	.5
9:40		120	.5	.5
9:45		92	2.5	3.25
9:50		68	2.25	4.
9:55		109	1.5	2.6

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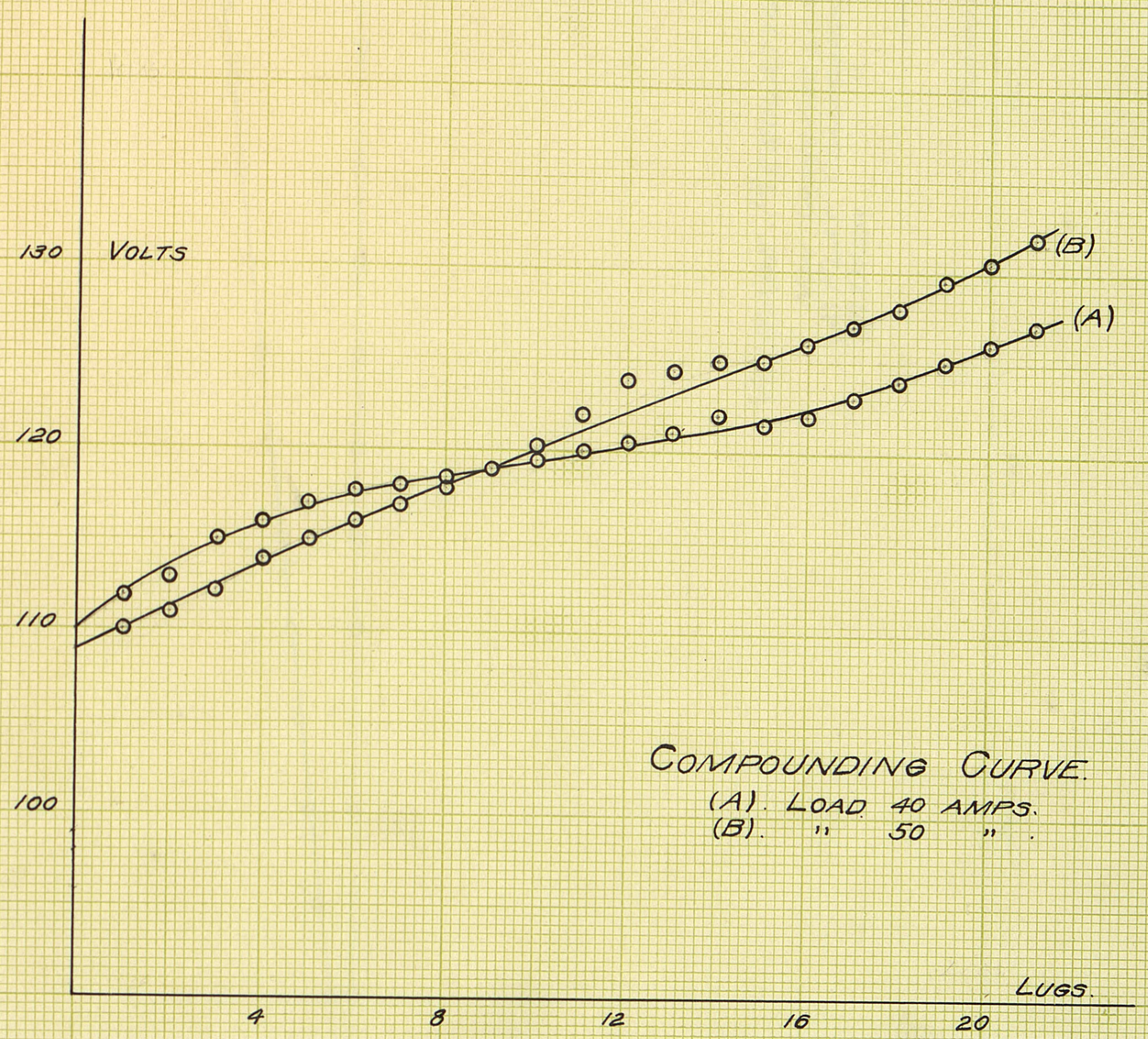
Data:-----Continued.

With Tirrell regulator. Flat compounded for 50 amperes.

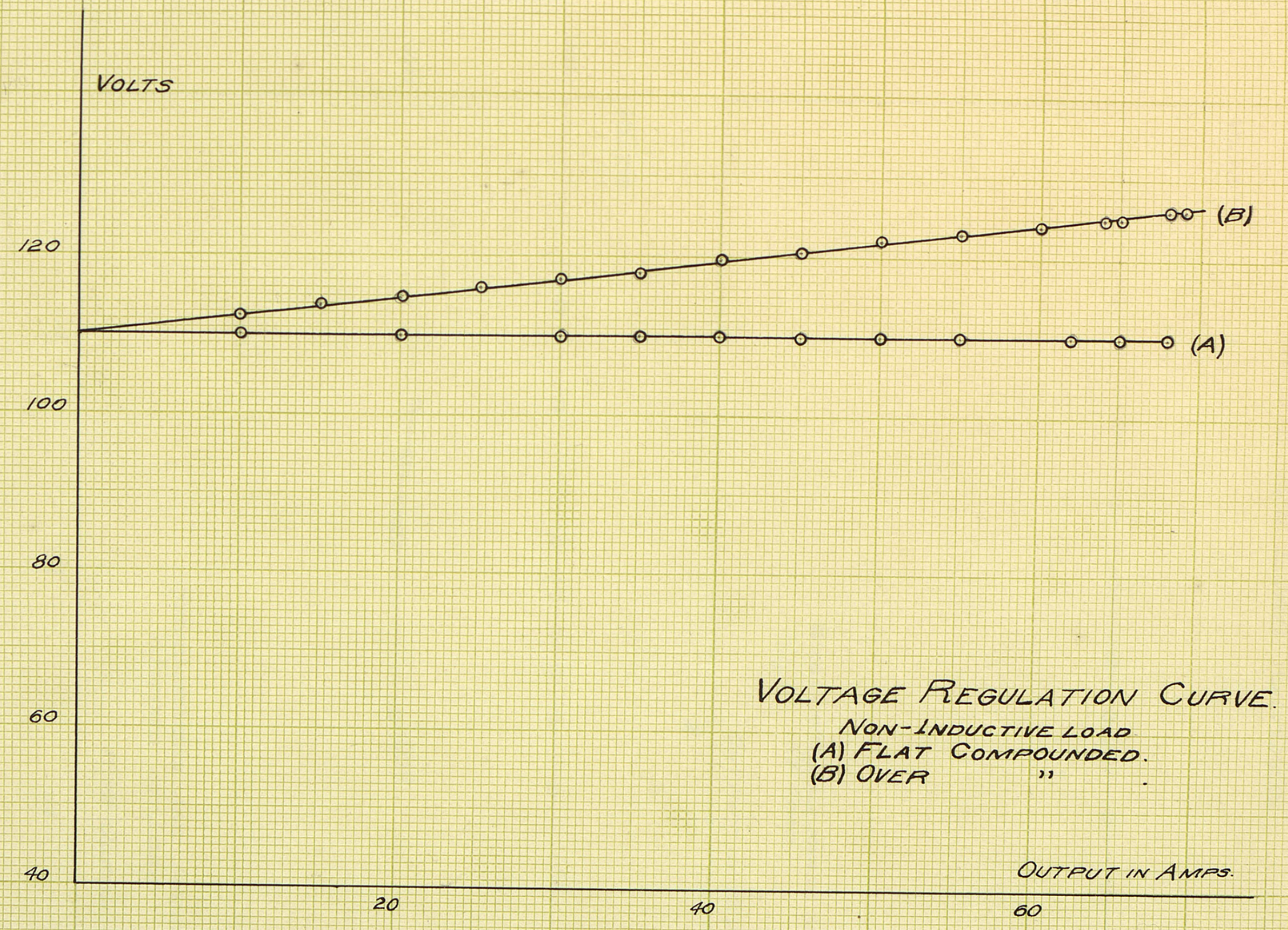
Time	Speed	Voltage	Watts	Output.
10:	1200	110	4.	2.75
10:05	1170	110	6.25	6:15
10:10	1220	110	1.8	3.6
10:15	1230	110	3.	2.
10:20	1240	110.5	1.	1.
10:25	1220	110	1.	4.3
10:30	1200	110	3.5	2.75
10:35	1180	110	5:75	5.35
10:40	1220	110	5.25	5.
10:45	1240	110.5	1.5	1.25
10:50	1200	110	1.5	4.75
10:55	1220	110	3.25	2.5
11:	1230	111	1.75	0
11:05	1180	110	6.75	4.8
11:10	1180	110	6.75	6.75
11:15	1240	110	2.4	1.
11:20	1170	110	5.2	6.3
11:25	1140	110	6.5	8.
11:30	1160	110	8.	7.5
11:35	1200	110	4.	3.15

SHEET #1.

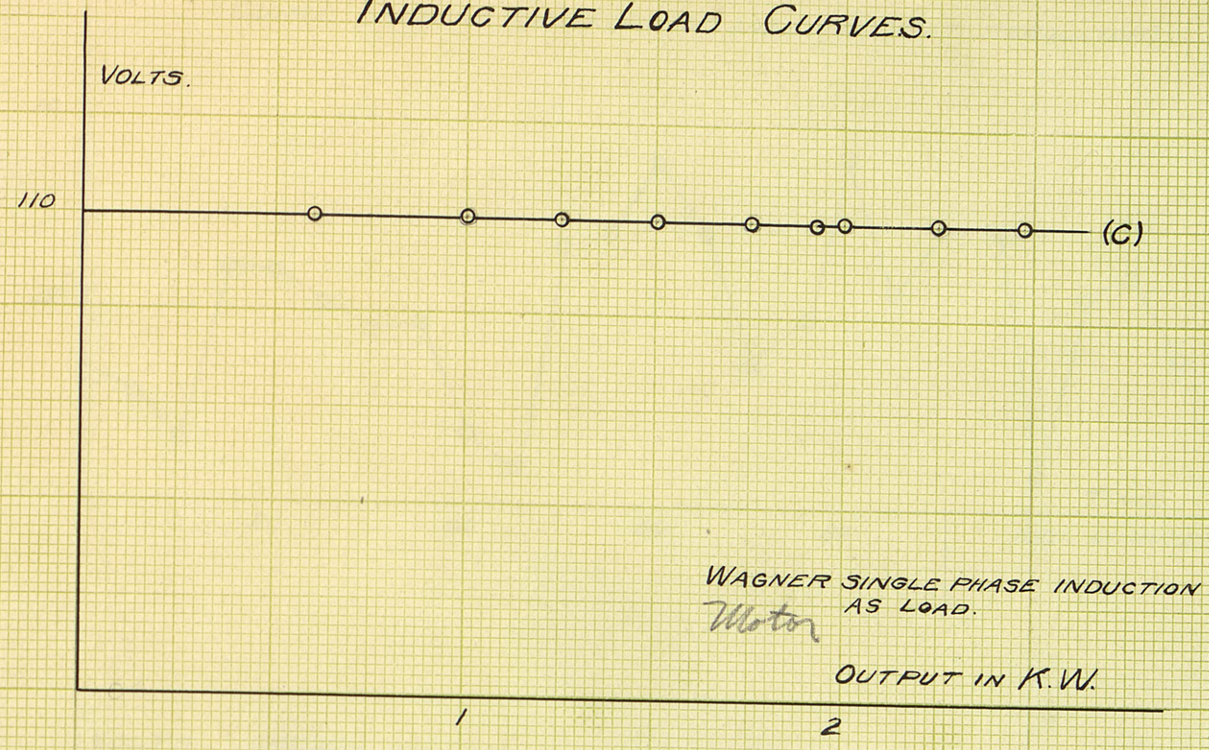


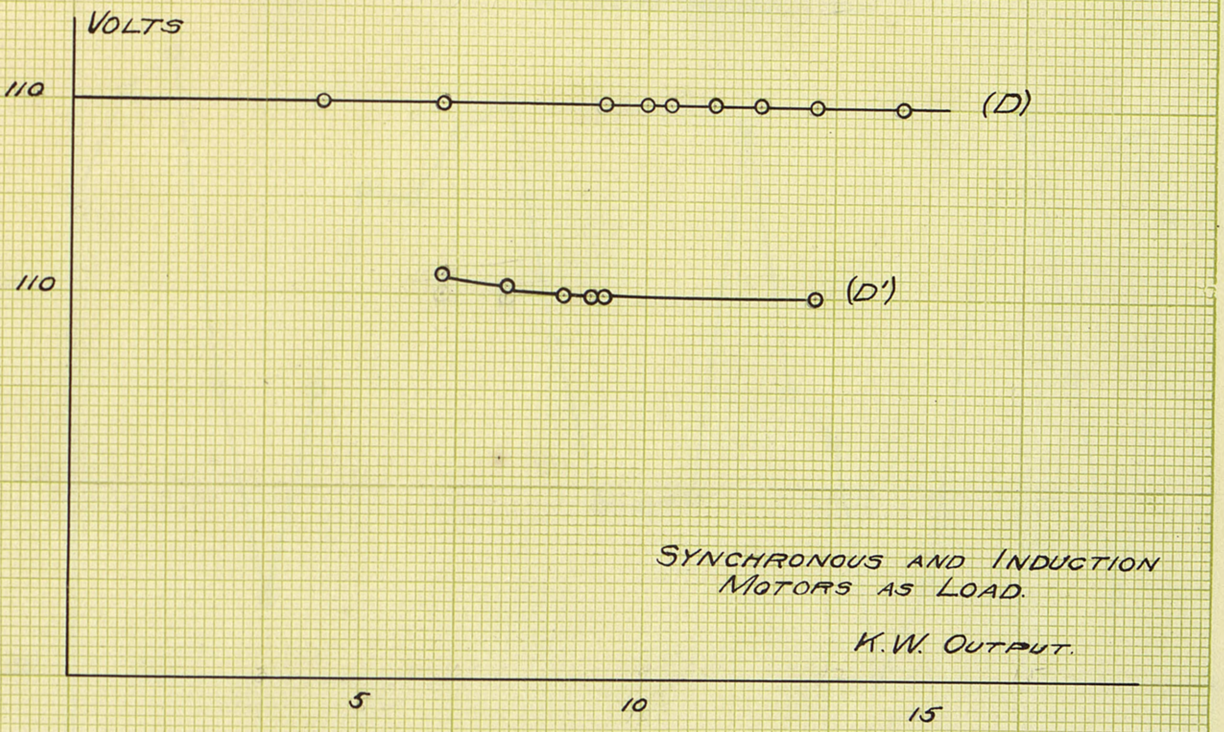
130
120
110
100
VOLTS
(B)
(A)
COMPOUNDING CURVE.
(A). LOAD 40 AMPS.
(B). " 50 " .
LUGS.
4
8
12
16
20

SHEET #2.

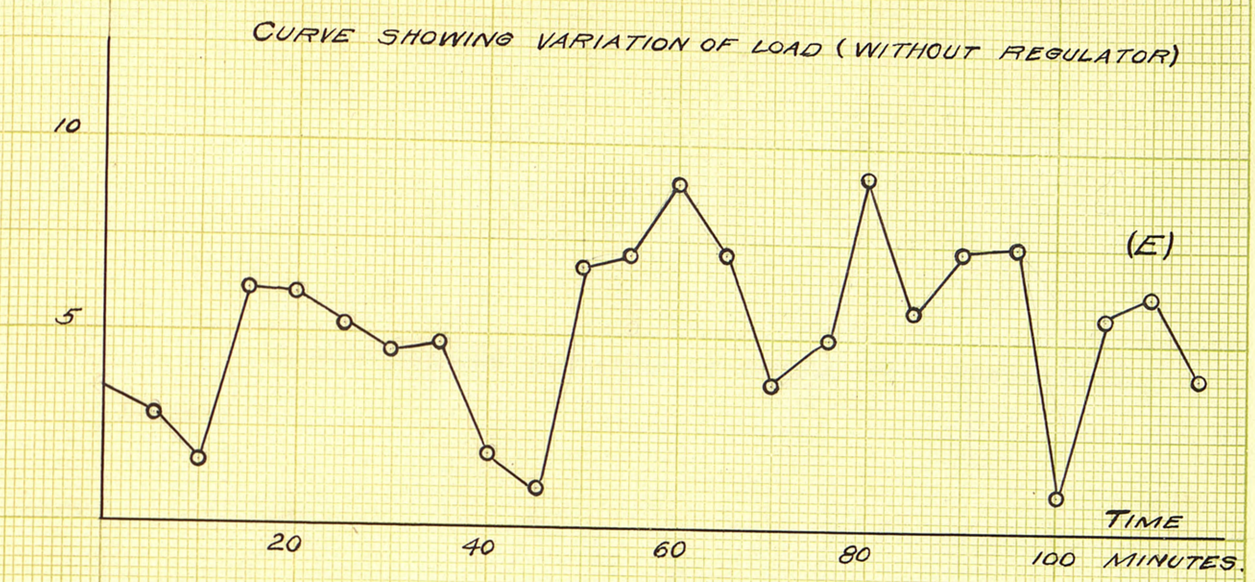

VOLTS
120
100
80
60
40
(B)
(A)
VOLTAGE REGULATION CURVE.
NON-INDUCTIVE LOAD
(A) FLAT COMPOUNDED.
(B) OVER "
OUTPUT IN AMPS.
20
40
60

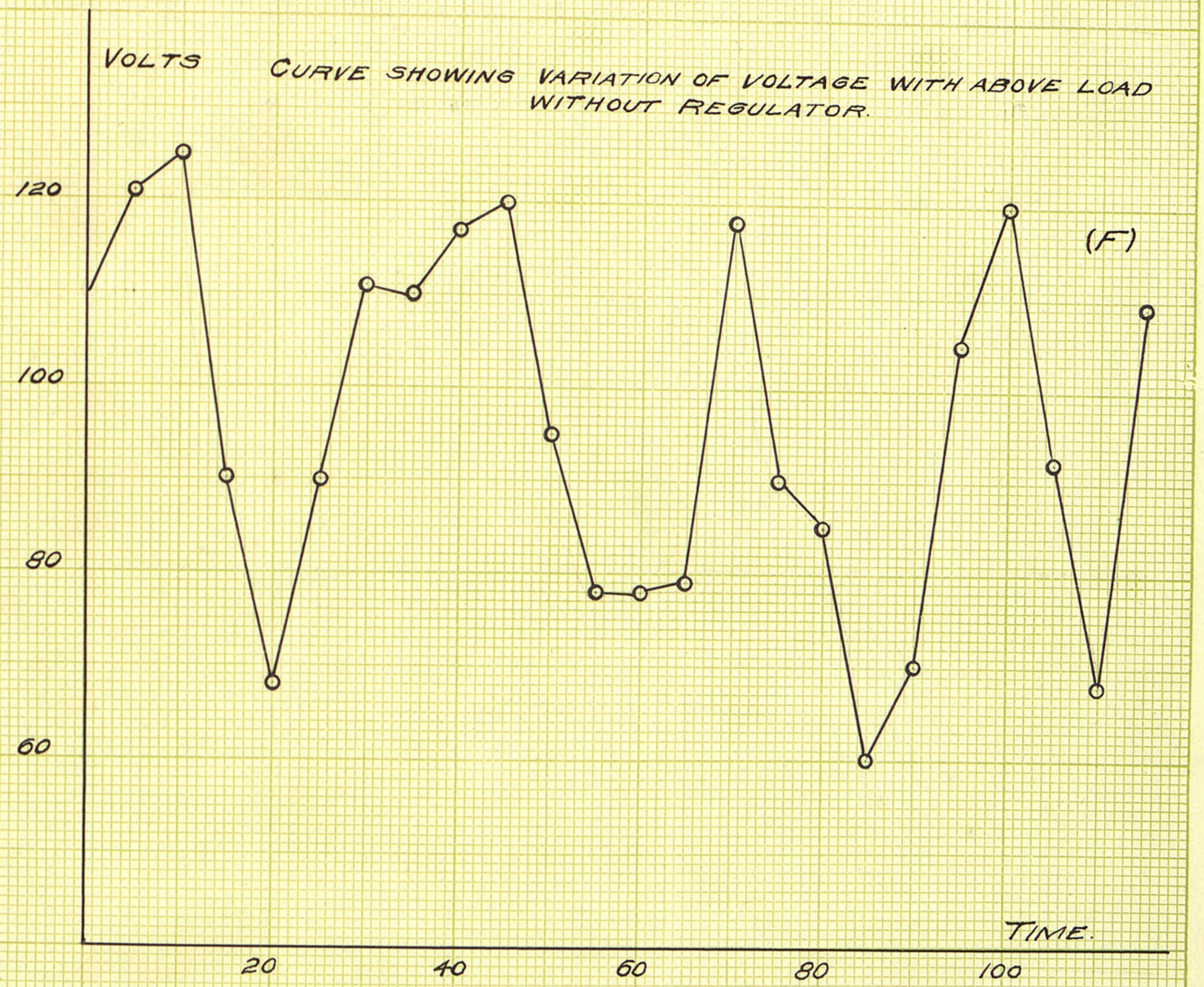
INDUCTIVE LOAD CURVES.

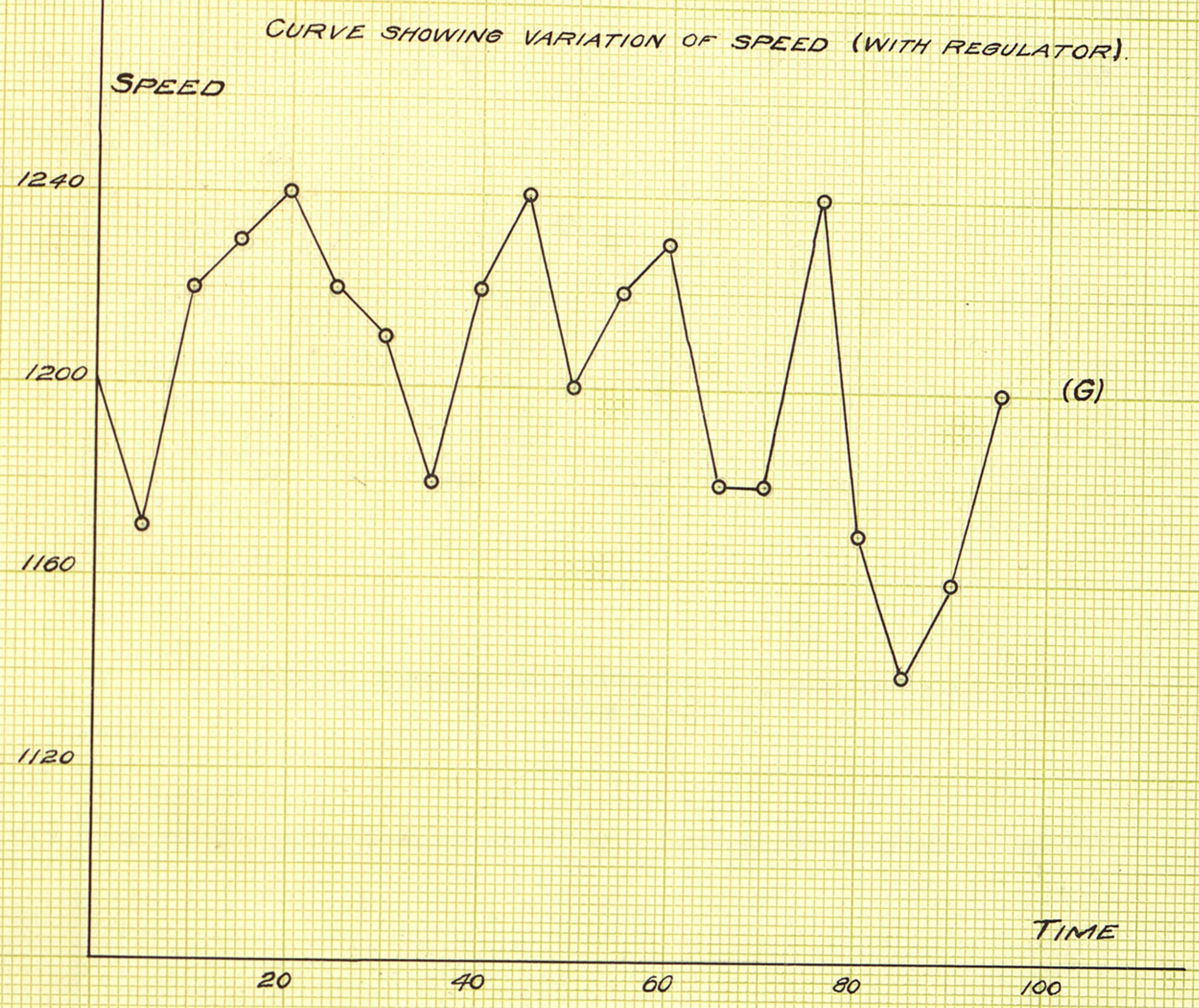




SHEET #4.


CURVE SHOWING VARIATION OF LOAD (WITHOUT REGULATOR)
10
5
(E)
TIME
20
40
60
80
100 MINUTES.


VOLTS
CURVE SHOWING VARIATION OF VOLTAGE WITH ABOVE LOAD WITHOUT REGULATOR.
120
100
80
60
(F)
TIME.
20
40
60
80
100


CURVE SHOWING VARIATION OF SPEED (WITH REGULATOR).
SPEED
1240
1200
1160
1120
(G)
TIME
20
40
60
80
100

The curves on sheet #2 were taken with the load on a single phase of the alternator, in which the current transformer was placed. The load was non-inductive and consisted of a water box. Curve (A) shows the regulator to have perfect control of a load of this nature, over the entire range of the machine. In this curve the alternator was flat compounded to give normal voltage, 110, and in order to do this the regulator was adjusted to give 110 volts at no load and a load of sixty five amperes, full load, was placed on the machine. The voltage was again adjusted to give 110 volts at this load by using the adjustable compensating winding. When flat compounded in this way the alternator voltage remained constant between zero and full load as indicated by the curve. The data for curve (B) was taken with the regulator adjusted to give an over compounding of 125 volts at full load. To over compound a given amount for a certain loadas 65 amperes in this case, the no load voltage was adjusted as before to give normal voltage at no load and the load was then thrown on the alternator and the voltage adjusted to 125 volts by using the compensating winding.. The voltage for intermediate points was then taken, allowing the previous adjustment to remain fixed. This curve is a straight lineand shows that the voltage varies directly as the load which is an important feature in voltage regulation as this allows the line drop to be automatically compounded for. This method of regulation has the advantage over the ordinary compounding method, in that its voltage curve is a straight linewhile in the ordinary method the curve depends upon the saturation of the polesand usually rises more rapidly for small than for large loads.

This of course leads to a variation of voltage at the receiving station as the line drop is directly proportional to the load.

Curve (C) on sheet #3 shows the voltage control of the Terrill regulator with an inductive load. In this test the Wagner single phase induction motor was operated as loadand as the curve shows the voltage control was perfect. This shows that the voltage control is more or less independent of the power factor which ranged from 45 to 70 in this test. Curve (D) on the same sheet also shows the control with inductive loads. The load was the G.E.Rotary converter run as a synchronous motor and the five H.P. three phase induction motor which were in turn loaded to give any required load on the alternator. With both motors operating the alternator was run at full load and as before there was no change in the voltage. This further illustrates the fact that the voltage regulation does not necessarily require a unity power factor. Curve (D') was taken before the regulation was properly adjusted and this curve shows a variation of two volts from full load to no load. After the counter poise had been readjusted the upper curve was taken showing the error in voltage control to be in the adjustment and not in the actual operation of the regulator.

The curves on sheets #s 4,5 and 6 were plotted to show the result of using the regulatoras compared to the voltage without the use of the regulator. In the first part of the data taken, plotted on #4, a non-inductive load was placed on the three phasesand the alternator was operated without the regulator or the use of the rheostat. The speed was kept constant at 1200 R.P.M. as it was impossible to load the alternator due to the armature drop and also the drop in voltage due to change in speed. The voltage was set at 110 volts at about one half the load to be carried and the field was then allowed to remain fixed while the load was periodically fluctuated. The load with its corresponding voltage was read and plotted in curve (E) with minutes as abscissas and load in kilowatts as ordinates. Curve (F) shows the variation of voltage with the preceding loads and shows the machine to have very poor voltage control, varying from 60 to 120 volts from full load to no load, although this is one of the characteristics of an alternator. Beyond nine K.W. it was impossible to load the alternator as the drop in voltage became so great that the output remained practically constant.

The curve on sheet#5 shows the variation in speed when the regulator was used as compared with the constant speed of 1200 in the preceding test.

Sheet #6 has the two curves corresponding to those on sheet #4, excepting that the Tirrell regulator was used in this test. Curve (H) is used to show the changes in load and indicates that the load was between 2 and 15 K.W., which is the full load output of the alternator. Curve (G) shows the variation of the speed during these changes of load, it being between the limits of 1140 and 1240 R.P.M. Curve (I) shows the voltage fluctuation under the preceding condition when the regulator is used. The greatest variation in voltage was one half volt while for all but two readings the voltage remained constant at 110 which shows that the regulation is perfect to one half of one percent for a load of this nature.

The regulator can not control the voltage absolutely constant for unequal phase loading as the CR drop in the armature varies for each phase according to the load on that phase The regulator keeps the voltage constant over the phase in which the regulator is placed but if the load is unequally divided the copper drop in the armature will not be the same and consequently there will be some change in the terminal over the different phases.

As the data on data sheet #11 shows the regulator will operate over a wide range of the prime mover. When the exciter is belt driven from the alternator as in this case the exciter has a corresponding reduction in speed and this is an added disadvantage (added) to the regulator. The ability of the regulator to control the voltage with the variations in speed is due to the fact that the D.C. magnet is placed directly over the exciter bus bars and will not act until the exciter voltage is up to normal, regardless of the speed. The A.C. magnet, from the alternator terminals, will not open the short circuit over the rheostat until the A.C. voltage is normal, so that with a change is speed the terminals voltage of the atletnator is practically independent of every thing but the adjustment of the regulator.