

THE TEST OF A ONE HORSE POWER SINGLE PHASE
INDUCTION MOTOR.

T H E S I S

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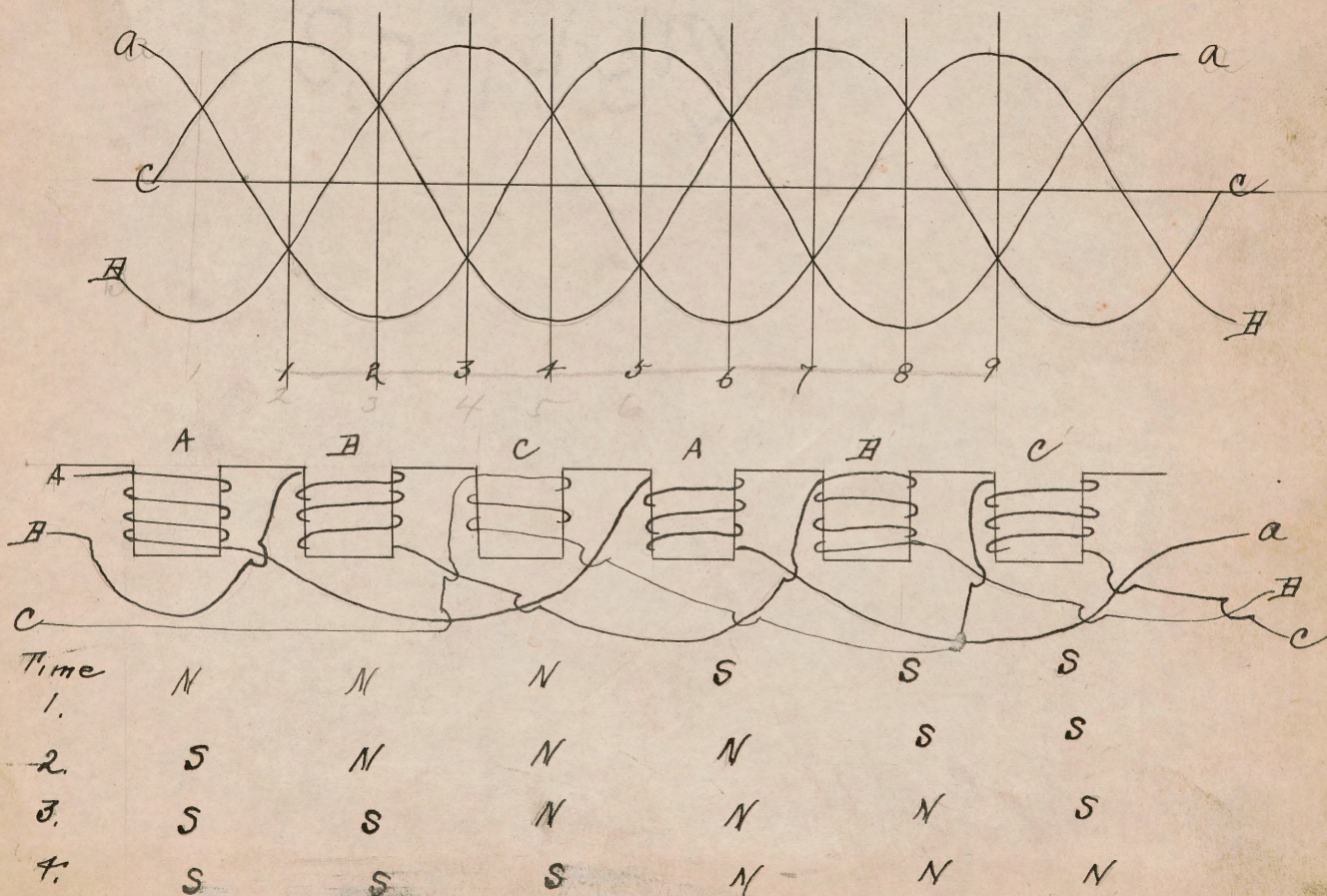
BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING.

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THE TEST OF A ONE HORSE POWER SINGLE PHASE INDUCTION MOTOR.

At the present time the alternating current motors in use may be placed in two classes, Synchronous and Induction Motors. However, a recently designed motor, similar in construction and operation to the series wound direct current motor, seems not to belong to either class.

The motor examined in this test belongs to the class of induction motors, and so for a better understanding of their operation it may be of some use to make a brief explanation of the general principles involved.



First considering the E.M.F. impressed on the field as three Phase, as represented in diagram I, and let the field be wound as in diagram II, each phase passing around the poles correspondingly lettered. Now at instant (1) of diagram I, it is evident that the poles will be as represented at time (1) in diagram II, at the instant (2), at time (2), &c. It is seen then that step by step the pole travels around the field and therefore the same effect will be produced as if the field itself were actually rotary. If the frequency of the E.M.F. be represented by f , and p represents the number of pairs of poles per phase, such a rotary field will make one complete revolution in $p \div f$ seconds.

The armature of the induction motor consists of copper bars placed in slots in a laminated iron cylinder. These are all connected in parallel by a conductor of low resistance. Induced currents are set up in these conductors or inductors by the rotating field, and as a wire in which a current is flowing always tries to cross lines of force at an angle with it, the armature is set in motion. The current in the armature is always proportional to the number of lines of force cut so in starting; as practically all the lines are cut a very large current flows. This reacts on the field demagnetizing it and necessitating in turn a large current there to offset that reaction. This large

starting current is the chief defect in the operation of induction motors. As the motor gains speed, the current in its inductors grows less and less, due to a less number of lines of force being cut. This calls for less and less current in the field. If there were no friction or windage the armature at full speed would revolve in exact synchronism with the field and there would be no current at all in the inductors and the current in the field would be just sufficient to magnetize its core. As it is, however, the armature lags behind the field till the product of the linking flux and the current to which the torque is proportional is sufficient to develop the required torque; and since more and more torque is required as the load is thrown on, the armature drops back farther and farther till, as before, the product of the current and the flux is sufficient to furnish the necessary torque. The ratio of the difference of rotative speed between the armature and the field at any instant to that of the field is called the slip. The frequency of the current in the armature is equal to the frequency of that in the field times the slip.

The foregoing explanation has been made with the three phase motor in view, but it is evident that it applies as well to the two phase. In the single phase motor the rotating field becomes rather a vibrating field; the lines of

force alternately expanding and contracting. Some consider it two rotating fields revolving in opposite directions neutralizing each other at certain points. The conditions resulting from either theory, however, are the same. But these conditions being somewhat different from those prevailing in the two and three phase motors, their principle of operation is somewhat different. In the first place they won't start without some outside assistance. This may be seen from the following diagram.

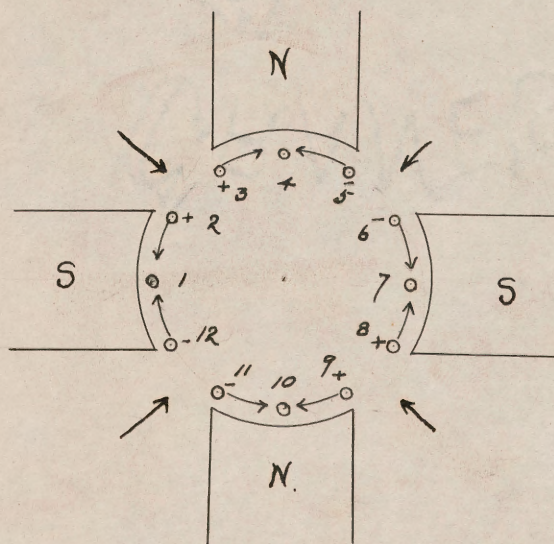


Diagram II.

First considering the intensity of magnetization as increasing, the lines will start about the wires around the fields and swell out, expanding in the directions indicated by the arrows between the poles, and in crossing the

the armature wires will tend to sweep them along with themselves; that is, the reaction in wire (2), for instance, will consist of an induced current coming up from the paper which will cause the wire to try to move toward (1); that in (3) will consist of the same kind of induced current, but as it is under a different pole it will try to go toward (4). The induced current in (5) is down and so the wire will try to go in an opposite direction to (3) or toward (4), also. But as they are of the same strength they will neutralize each other. In the same manner it will be seen that 6 neutralizes 8; 9, 11; and 12, 2, and there will be no tendency anywhere toward rotation. The existing condition may perhaps be better shown by the magnetization and induced current curve. Supposing these to be sine curves and that there is no self induction, when the intensity of magnetization is a maximum, the current will be zero as the lines of force are then changing least. So the curves will be as follows.

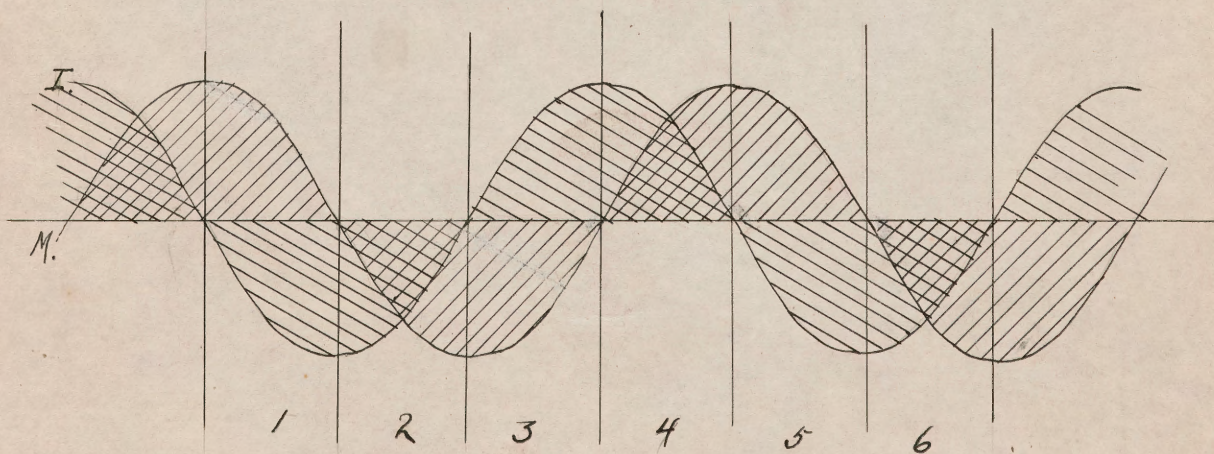


Diagram III.

As the rotative force is proportional to the product of the linking flux and the current, during the first $1/4$ cycle it is proportional to the product of the areas differently shaded in section (1) on the diagram, and the armature will tend to revolve in a certain direction. Call that direction (-) for the quantities multiplied together are of different signs. During the next $1/4$ cycle the conditions will be as shown in section (2), the product of the differently shaded portions being equal to the torque as before. But it is evident that this product is equal to that of section (1). However, as the quantities involved are of the same sign, the direction of the rotative force will be opposite to that in (1) and the one will neutralize the other. From the same reason it is evident that the rotative forces developed in sections 3 and 4 will also neutralize each other. So it is seen that during any complete cycle there is no tendency to rotate. As before stated, this would be the condition if there were no self induction in the inductors of the armature; but as there is self induction, the actual condition existing in each wire may be represented by the following curves:

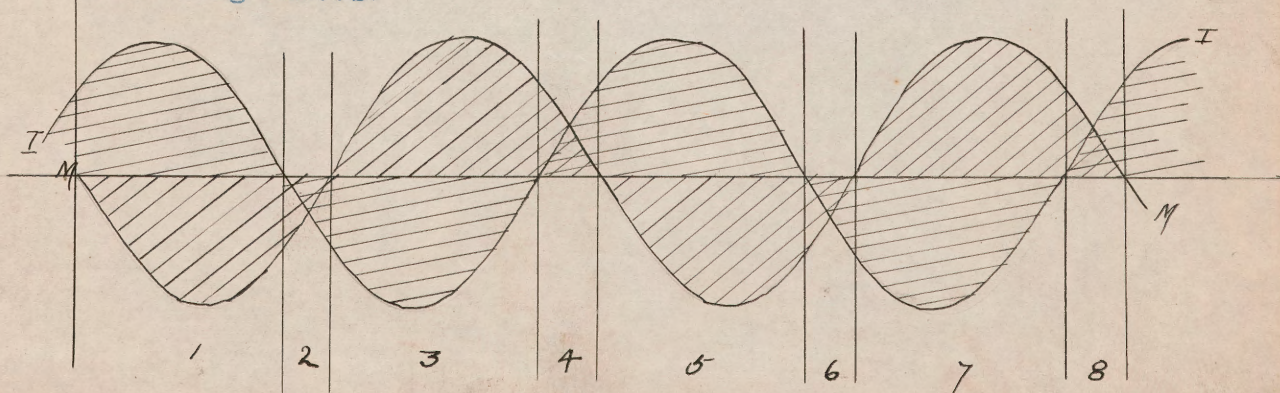


Diagram IV.

It is evident from the previous discussion, that there will now be a resultant rotative force in the direction called (-). Considering this condition to exist in wire (3) of diagram (1), it will continually tend to go toward (4). However, at the same time wire (5) will leave a similar condition existing in it, being similarly placed in regard to the pole. But the **force** will be in the opposite direction so neutralizing the force of (3); and there is still no tendency to rotate. Suppose now the armature be given a rotary motion from some outside source. On account of the current lagging behind the E.M.F., as explained previously, when the pole is passing through its zero value the current in the wire under the pole will not yet have reached its maximum, but it will do so a little later, say when the wire containing it has passed to the edge of the pole. As the pole will already have reversed, the lines of force will be swelling out and in crossing the wires will create a greater torque in the wire containing the maximum current, which we are supposing is at the edge of the pole. The wires behind having less current, their torque will be less and though it is opposing the other, it will not be sufficient to neutralize it. And there will be an effective torque remaining. If this remaining torque is sufficient to overcome the friction of the motor, the armature will continue to revolve, increasing its torque with its speed until nearing synchronism, when it decreases again due to the decreasing current.

In starting an inductive motor then, it is evident that the wires containing the maximum current must be unsymmetrically placed with respect to the poles. One way of accomplishing this is to practically make the motor a two phase one by establishing another pole between the already existing ones, in which the current will be leading. This may be done by placing a condenser in series with one wire.

In the motor under test the desired conditions for starting are established in an entirely different way. To explain its principle it will first be necessary to describe in brief the construction of the armature. Instead of the inductors being connected in parallel, as in the ordinary squirrel cage rotor, the armature is wound in series as in the direct current motor. The brushes in their neutral position connect the coils under the centres of unlike poles. However, in running they are moved to one side or the other of that position, according to the direction of rotation desired.

The following diagram will then represent the existing conditions.

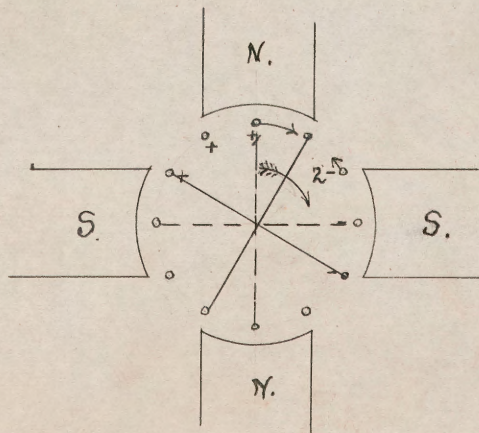


Diagram V.

The dotted line represents the neutral position of the brushes, and it is evident from the previous discussion that all the forces are balanced for that position, and there is no tendency to rotate. Examining the conditions with the brushes in the running position, as shown by the full lines, first with the lines of force increasing. The current then will be up in (1) and down in (2) and of the same value in each, as the armature wires are in series. However, as they are both in the same kind of a field, their tendency for rotation will be in opposite directions. But as (1) is in a stronger field than (2), it exerts greater torque. However, on the current collapsing, if there were no self induction the conditions would be exactly reversed and so in operation the torque for $1/4$ of a cycle would be in one direction and for the next $1/4$ in the opposite, and so on, with no resulting motion. But, taking into account the self induction, the current lags behind the E.M.F.; and there is still a tendency to rotate even when the magnetization has become a maximum. And as the current does not come to zero till after the lines of force have started to collapse, the torque caused by the collapsing lines is not as great as that caused by the increasing lines. The difference between the two is effective for rotation. This condition is the same as shown in diagram (3).

When the motor has attained a sufficient speed so that its torque is sufficient to take care of its rated load, by means of a centrifugal device the brushes are thrown off and

at the same instant a short circuiting ring is pushed up against the armature, thereby connecting its inductors in parallel as in the ordinary squirrel cage rotor. This method of starting seems to work very satisfactorily as it is entirely automatic, and moreover furnishes a comparatively large starting torque.

This particular motor is one manufactured by the Wagner Electric Co. of St. Louis, Mo., under the patents of Pillsbury and Schwedtwan. It is known as type B and is designed for a frequency of 60 cycles and an E.M.F. of 104 volts and is intended to develop 1 H.P. at 1800 R.P.M. with a current consumption of 13.2 amperes. The test shows this is about what it does.

The following data gives as far as obtainable from the direct examination of the motor, its principle constructive features.

I. The Field - Built of laminated disks.

Inside Diameter -----	6.81"
Total Width -----	3.31"
No. of Poles -----	4.
Slots to a pole -----	8.
Depth of slots -----	1.125
Width of slots -----	.375
Series Wound distributed winding	
No. of wires to a slot -----	16.
No. of turns per pole -----	64.

Average length of one turn, 16"
Resistance in ohms ----- .55
Size of wire - B and S No. 18
Air Gap ----- .0625"

II. The Armature - Built of laminated disks.

Diameter ----- 6.75"
Width of face ----- 3.44"
No. of Slots ----- 39.
Inductors in a slot ----- 2
No. wires in each inductor, 4
Size of wire - B and S No. 18.
Armature wound same as that
of a four circuit direct current,
motor.

III. The Commutator - Radial.

No. segments ----- 78.
Brushes ----- 4.

Before beginning the test all the instruments to be used were carefully calibrated. A Weston Millivoltmeter used with a shunt, being found to agree almost perfectly with a Siemens Halske Precision Millivoltmeter, was used as the standard of reference for the alternating current ammeter. The E.M.F. was measured by a Kelvin Multicellular voltmeter compared with a Weston direct current voltmeter while in the position in which it was used. Some trouble

was found in calibrating the wattmeter for it was found to read differently on the direct current, even though reversed readings were taken, from what it did on the alternating current. However, considering the fact that it was finally calibrated by the alternating current under exactly the same conditions as when used for the test, the results due to it may be considered reasonably reliable. It might be of some interest to consider exactly what amount of error could be due to the instruments used. Considering that any instrument may be read accurately to the tenth of the smallest division if not smaller than a millimeter, the following table represents the percentage of error liable in each instrument:

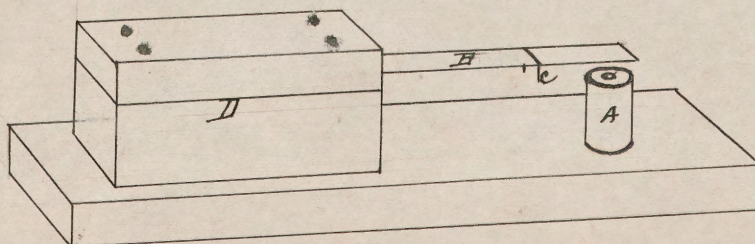
Instrument.	Error Due to		
	Incorrect Reading	Calibration	Total
A.C.			
Ammeter	.2	0	.2
Voltmeter	.1	0	.1
Wattmeter	.1	1.	1.1

Now, considering the fact that during the test both the E.M.F. and the current were continually fluctuating, these errors may have been doubled. Considering it so the power factor may be in error to the extent of .65%; the efficiency will practically not be affected at all.

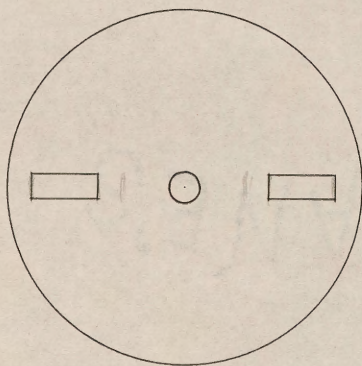
The above estimates of error are based on average loads. With the smaller loads the per cent. of error is larger than

stated and with the higher ones it is less.

In measuring the torque and output an improved prony brake was used. This consisted of a wooden arm to each end of which was fastened a strap of heavy cotton webbing which could be tightened by a screw. The bar was prolonged and provided with a vertical rod working in bearings by which the force of rotation could be measured at a distance of exactly 4 inches from the axis. The rod rested on a platform balance reading to ounces. The brake was clamped on to a hollow brass pulley which was kept cool by filling with water. The speed was taken by a speed counter with full minute readings each time. In considering the slip of the motor, it was found impossible to calculate it on the basis of the rated frequency of the supply current on account of its variableness, due to the fact that the same machine carried a converter supplying current for motor circuits. It was therefore found necessary to arrange an apparatus so as to obtain at any instant the relation between the actual frequency of the current and the speed of the motor at that instant. To accomplish this a small apparatus, as shown in the following sketch, was constructed.



B is a sheet iron strip about a centimeter wide clamped in the support D. C is a rider on the strip and A an electro magnet. When an alternating current is sent through the electro magnet, if its frequency is the same as the natural period of vibration of the strip, the strip will be set vigorously into vibration. If not, it will only vibrate slightly or not at all. However, by means of rider C, the period of vibration of the strip may be brought into synchronism with that of the current. In using this apparatus a cardboard disk containing two slits, as shown in the diagram, was fixed to the motor armature, and the vibrations of



the bar were observed through the slits. It is evident that if the motor was revolving exactly in synchronism with the current, it being four pole each time the slit would come around it would find the strip in the same place and the strip would appear sta-

tionary. However, as soon as the speed drops, the strip is seen a little ^{later} ~~earlier~~ in its vibration each successive revolution and so it appears to go up and down and to apparently make complete vibrations. It is evident that the number of complete vibrations the strip thus appears to make per minute is the slip in cycles per minute.

The following tables give the data and results as obtained.

DATA FOR CALIBRATION OF AMMETER.

Millivoltmeter Reading.	1.3	2.92	5.36	8.38	9.36	11.7	14.52	17.2
Electro Dynamometer Reading.	2	8.9	25.4	60.3	74.8	120	188	260.2
Alternating Current Ammeter.	2	3.5	4.6	7.1	11.5	13.42	14.98	16.52
Electro Dynamometer Reading.	2	7	15	36	116	173	227	302

DATA FOR CALIBRATION OF WATTMETER.

DATA FOR CALIBRATION OF WATTMETER.							
Increasing Current.	Wattmeter Actual Reading	Wattmeter Corrected Reading	Ammeter Reading	Electro Dynamometer	R. M. F.	Corrected I.	True Watts.
2.02	1.42	2	2	112		1.5	168
3.3	2.85	3.7	9	111		3.2	352.5
6.95	6.6	7.5	39	110		7.0	770
9.52	9.18	9.65	75	110		9.4	1034
11.9	11.42	11.84	127	109		12.1	1320
14.5	13.9	13.9	193	106.5		14.8	1578
Decreasing Current.							
14.05	13.4	13.78	182	106		14.6	1549
12	11.55	11.80	126	107.5		12	1290
10.2	9.82	9.80	78	111		10	1110
7.35	7.05	7.5	39	110		7	770
3.89	3.40	3.9	7	112		3.3	370
2.21	1.61	2	1.5	112.5		1.5	169

AVERAGE OF CORRESPONDING LOADS.

True Watts	168.8	361.2	770	1072	1305	1563.5
Wattmeter Reading.	151.0	312.	682	950	1148	1365
Difference.	17.5	49.2	88	122	157	197.5

See Plate I.

DATA AND RESULTS OF TEST OF 1 H.P.

INDUCTION MOTOR.

Slip in per cent.	R. P. M.	Slip in cycles.	Load in lbs.	Electro Dynamometer.	Voltmeter Reading.	Ammeter Reading.	R. M. F.	True Watts.	True Amperes.	Power Factor.	Brake H. P.	Efficiency.
.42	1829	15	0	58	2.65	8.7	112	295	8.4	.318	0	0
.72	1830	26	2	64	3.65	8.9	111	408	8.6	.426	.2324	.426
1.08	1822	39	4	80	5.5	9.9	112	620	9.8	.565	.463	.557
1.55	1820	56	6	95	7.19	10.6	111	812	10.6	.69	.693	.637
2.47	1808	88	8	135	9.45	12	111	1070	12.3	.784	.919	.641
3.44	1789	124	10	195	11.53	13.9	111.5	1311	14.7	.80	1.135	.645
4.78	1756	172	12	295	14.40	16	111	1655	17.6	.847	1.338	.603

The results of this test are plotted on Plate II.

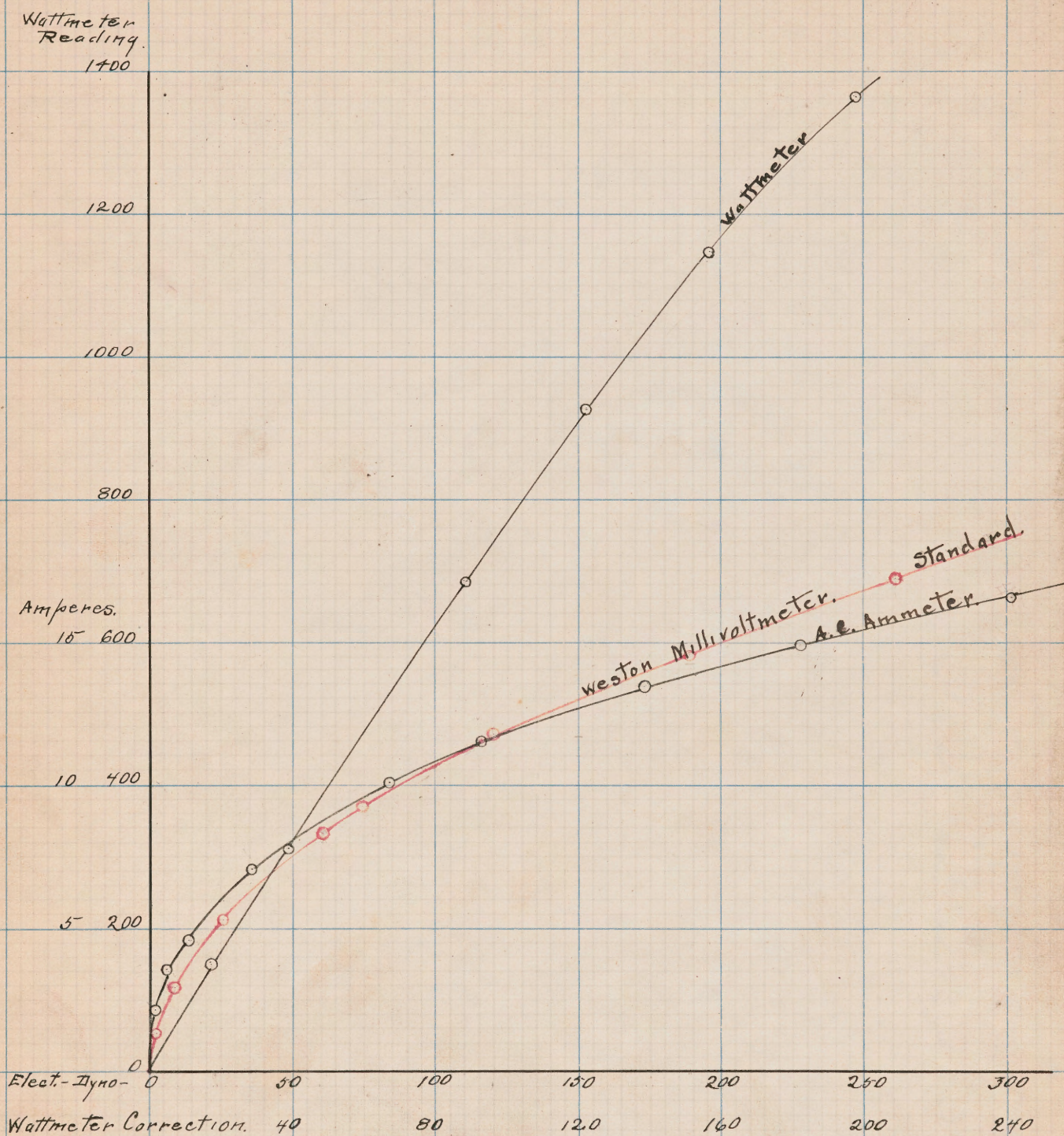
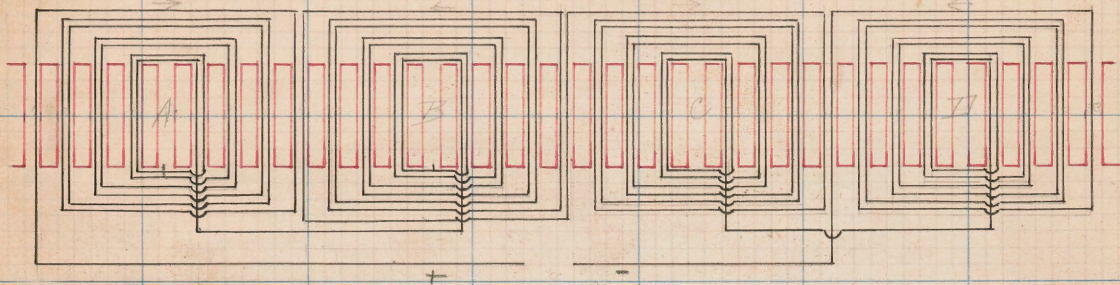


Plate I.

Curves of Weston Millivoltmeter and Electrodynamic
 Curve II. Between Alternating Current Ammeter and Electrodynamic
 Current. 15.1.1904. Weston's correction curve for

Winding of Field.



This winding is for a field.

