EXPERIMENTS UPON CERTAIN COMMERCIAL ELECTRIC METERS.

By ALBERT L. CLOUGH.

INDEX.

p

Introduction. 1

Description of Thomson Direct Reading Wattmeter. 9

Method of testing Thomson Meter upon direct current. 18

Record of time load tests on Thomson meter # 5114 22.

Conclusions upon above. 27.

Precision of above tests. 29.

Time load tests on Thomson Meter # 7971. 32.

Conclusions upon above. 33.

Method of Alternating current tests upon Thomson meter. 34

Alternate current tests upon Meter # 5114 36

Same upon Meter # 7971 37.

Precision of above. 38.

Calorimeter tests 39.

INDEX (CONTINUED.)

P

Tests upon proportionality of current & speed. (Meters 5114 & 7971.) 43.

Energy dissipated in Thomson Meter. 48.

Sensitiveness of Thomson Meter. 49.

Converter tests by the Thomson Meter. 51.

Tests of Thomson meter upon highly inductive load. 56.

Description of Shallenberger Meter. 64.

Time load tests upon above. 67.

Sensitiveness of above. 70.

Energy dissipated in above. 71.

Description of Walker meter. 74.

Tests upon Walker meter. 78.

Energy dissipated in above. 81.

Sensitiveness of above. 81.

General summary of results. 82.

INDEX TO PLOTS AND ILLUSTRATIONS.

P

Photograph of Thomson Meter (#5114) 8
" " " " #(7971) 16
Plots of proportionality of speed and currents (Thomson Meter). 43,45.
Plot of energy loss in the various meters. 47.
Photo. Shallenberger meter. 63.
Plot of time load tests upon above. 69.
Photograph of Walker meter. 73.
Sample record of Walker meter. 80.

———o———

Experiments upon certain Commercial Electric Meters.

With the growth of electric lighting and its extension into such places as dwelling houses in which the number of lamps burning is very variable, the meter system, as a basis for the determination of the charges to be paid by the consumer, is finding more and more favor, and is rapidly supplanting the hitherto almost universally used contract system. The advantage of being enabled to pay for exactly the amount of energy actually consumed is obvious, The electric meter is hence becoming a more and more important factor in the business, and many forms of more or less value have been devised to meet the demand which has arisen.

These instruments depend for their operation upon the three principal physical effects of the current—its chemical action, its thermal action and its electromagnetic effect; they have been so designed as to be direct reading, or so arranged as to require some process to be applied to as-certain the amount of electrical energy accounted for; — as weighing the plates in the electrolytic meter, for instance.

The property of "direct reading" however is an obvious advantage of great value and characterizes the most of the widely used types of instrument.

It was desired by the writer to obtain specimens of as many different types of meter as possible, especially of those actually in extended commercial use, and with that object in view, requests were made of various companies for the loan of one or more of their instruments.

The Thomson Direct Reading Wattmeter, The Aron Electric Counter, The Shallenberger, Walker, Wood, Slattery, Geyer-Bristol & Edison meters comprise those to obtain which an effort was made.

Meters of the Thomson Shallenberger and Walker types, only, were received however, and the work was necessarily restricted to these.

This failure to obtain the desired number of types has been a severe disappointment to the writer.

Both the Thomson and Shallenberger meters are of the direct reading motor type and are in very extended use in this country. The Thomson is of comparitively recent introduction, which the Shallenberger was the first practical direct reading meter to be brought forward, at least in this locality. They are both of a very neat, compact form, similar in appearance to the well known gas meter and not so delicate as to require a skilled electrician to place them in operation.

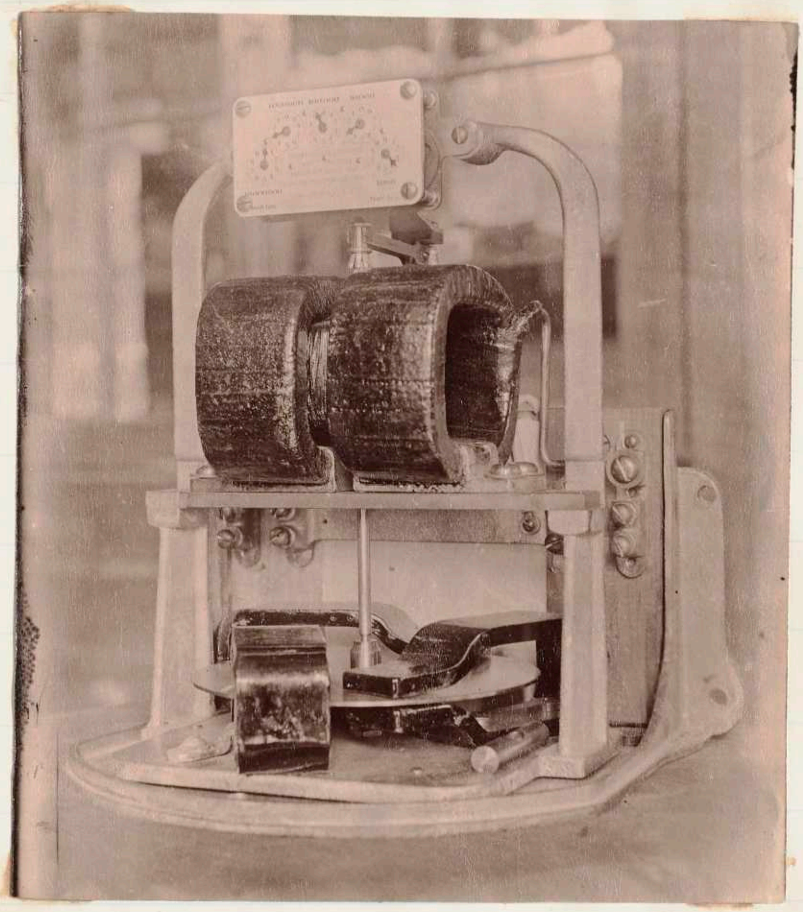
The following points are thought to be among the requisites of a suitable electric meter and the tests were made with them in mind.

(1.) The meter must be accurate at all rates of consumption of electrical energy within its rated capacity, that is: its indications at all rates of working must correspond within commercial limits to those obtained from standard electrical measuring instruments

(2.) It must require the expenditure of a minimum of electrical energy in its operation, thereby avoiding both a drop in potential at the lamps with its consequent waste, as well as undue heating in the instrument.

(3.) It must be sensitive, that is, it must begin recording as soon as an expenditure of energy begins to take place.

(4.) It must furnish its indications with a minimum of trouble, be as simple and inexpensive in construction as may be and must require very little attention.



Thomson Meter. #5114

The Thomson Recording Watt-meter.

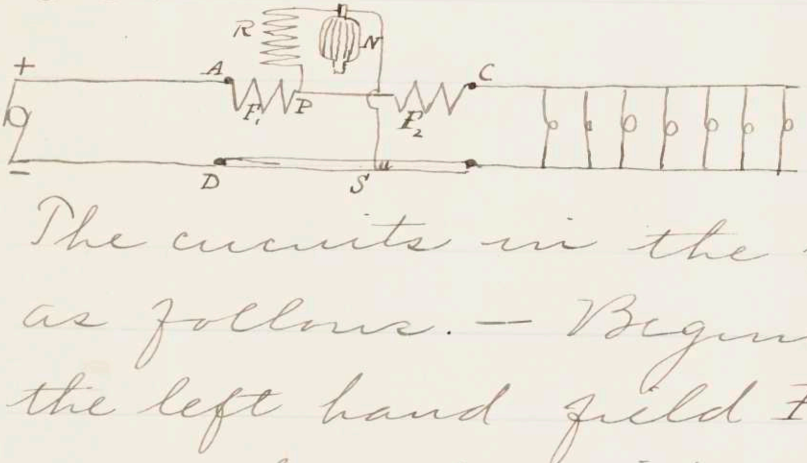
This instrument is a new and exceedingly interesting meter. It is in brief an electric motor which drives a train of clock-work acting as a revolution counter, and which has its speed properly regulated by a retarding device so that it is proportional to the energy passing. The field of the motor consists of two rectangular coils of coarse wire through which passes the main current supplied to the circuit, while the armature, in series with a non inductive resistance, is connected as a shunt across the mains.

The armature is one of the ordinary closed coil form and is provided with a commutator of pure silver and in common with the rest of the instrument is free from iron. The retarding apparatus embodies a very beautiful principle:— that of the absorption of mechanical energy by a mass of metal moving in a magnetic field, in the form of eddy currents. The frame is made of brass. From its floor rise two uprights that carry the field coils, which are placed quite close together so as to concentrate the field about the armature.

Between, and partly enveloped by the fields is the armature, carried on an upright shaft resting on a jewelled pivot on the floor of the frame. Just above the pivot the shaft bears the copper disc in which the dampening eddy currents circulate, and which is arranged to run with very slight clearance between the poles of three permanent horse-shoe magnets of considerable strength. Above the armature the shaft carries the commutator upon which press two little brushes, and above this the shaft bears a worm which meshes with the first gear of a revolution counter which is provided with dials reading directly to watt-hours. The upper end of the shaft is not confined in a rigid bearing, but is allowed to rest loosely in a little tubular piece projecting from above.

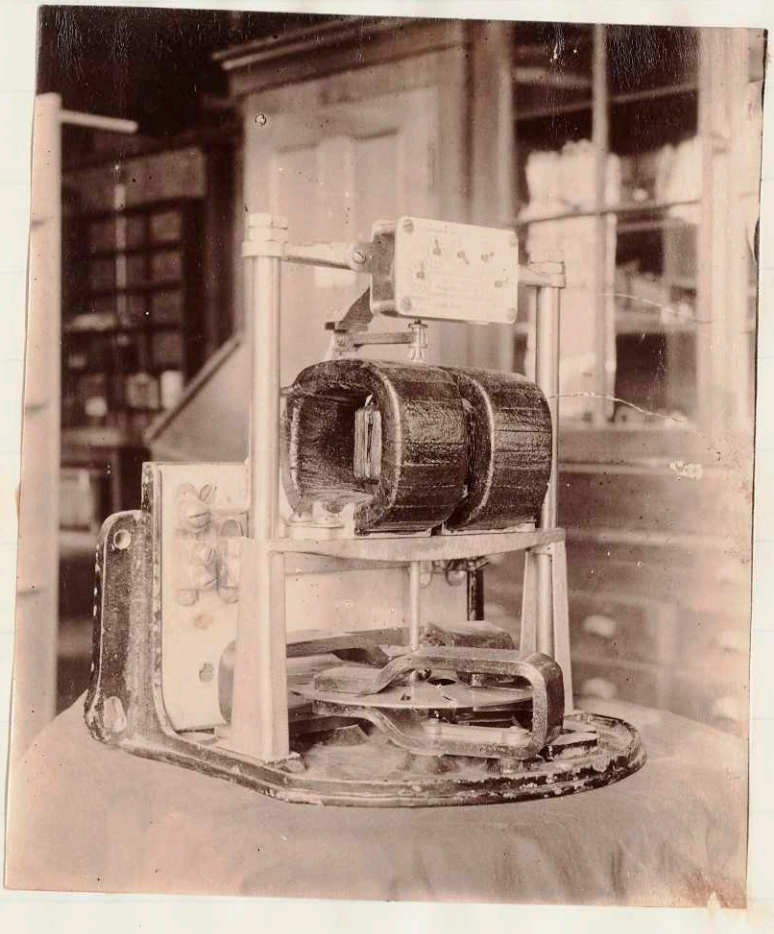
Concealed in the back of the meter is a very important adjunct, the auxiliary resistance, which is, as before stated, in series with the armature.

The meter is covered with a japanned metal case which fastens on securely with a single screw, and is sealed in place by a lead seal such as is used on the doors of freight cars. There is a small spirit level provided to aid in the proper installation of the meter.



The circuits in the meter are as follows.— Beginning at the left hand field F_1, the main current enters it at A passes thence through the right hand field F_2, out of the meter at C, through the lamps and thence back to the brass strip S and out at D. From the minus terminal P of the left hand field there starts a circuit which includes the back resistance R the armature N and thence passes to S. It is thus seen that one of the fields is always energized to some extent. This is for the purpose of developing a small constant torque of a magnitude all but sufficient to overcome the moment of friction of rest of the pivot. Upon any slight increment in the field strength due to the commencement of the main current, friction is overcome and the meter starts. This is an exceedingly beautiful device which renders this meter very satisfactory in point of sensitiveness. To show its effectiveness; — one of the meters experimented upon which was subjected to the vibration of the building was seen to be slowly revolving while there was a "dead open circuit" in the house leads of the instrument. When the vibration was suppressed the meter stopped, owing to the increased friction of the pivot,

It reads in Watt-hours and thus takes account of the actual electrical energy furnished, which is not the case with meters read-



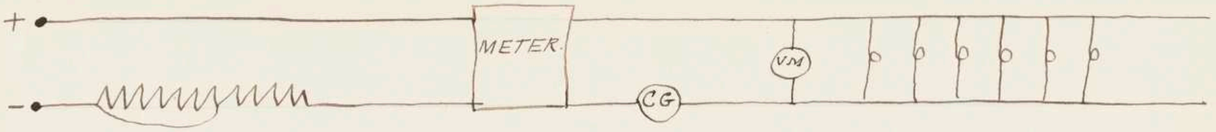
Thomson Meter. #7971

ing in ampere-hours.

The meter first received was numbered #5114 was rated at 10 amperes and 100 volts and was adapted for use on either alternating or direct current. Later another meter of the same capacity was received numbered #7971 and of a slightly modified form; the copper disc being slotted to reduce its weight, the frame of the instrument being remodelled and the disposition of the magnets changed. These two meters will be designated by their numbers.

Direct current Time-Load Tests on the T.H. meter.

In all the direct current tests the instrument under experimentation was connected to the 110 volt mains, in one of which was an adjustable resistance to reduce the voltage to the required amount, and also a Thomson Graded Galvanometer (#205.) carefully calibrated by comparison with a Weston Ammeter. #(438) The meter measured the energy furnished a bank of lamps across the terminals of which was connected a Weston Voltmeter.



The circuit employed was one on which there was very little current except that required for this work; this fact together with the automatic regulation of the dynamo contributed to furnish very constant voltage. A test comprising 1/4 min. voltmeter readings for 5 min. performed in the morning of a run was found to check very closely with a similar test in the afternoon. This showed that it was unnecessary to take very frequent voltage readings. The current was read many times during the day but the variation was so small as really not to necessitate this.

The procedure was, to start the meter in the morning on the lamp load, at a noted time; to take volt and ammeter readings at intervals during the day, and at about 5 o'clock or so to break the circuit at a noted time. The product of the mean potential in volts, the mean current in amperes and the difference of time in hours was then compared with the difference in watt-hours between the final and initial readings of the meter.

The ratio $\frac{\text{Watt. hrs by meter}}{\text{Computed watt-hrs}} = \eta$ was used as a measure of the accuracy of the instrument.

Tests of this kind were made at currents approximately corresponding to 1/4, 1/2, 3/4 and full load and at about 110 volts potential. Then by means of the auxiliary resistance the voltage used was cut down to about 90 volts and an exactly similar series of tests carried out. This was done in order to test the instrument as a watt-meter proper by varying both factors.

The tests. Direct current.
Thomson Wattmeter #5114
110 Volt. series.

Full load. (1.)

Mean volts.	107.5
" amperes.	9.87
Time in hours.	7.04
Calculated Watt. hrs.	7576
Watt hrs. by meter.	6820

$\frac{\text{Watt. hrs by meter}}{\text{Watt. hrs. calculated}} = \eta = 90.0\%$

Full load (2.)

Mean volts.	107.5
Mean Current.	9.87
Time.	7.667
Calc. watt hrs.	8134
Obs. " "	7380

$\eta = 90.7\%$.

Full load (3.)

Mean volts.	107.5
" amperes.	9.87
Time.	2.72
Calc. watt hrs.	2882.
Obs. " "	2600.

η = 90.0 %

3/4 Load. (1.)

Mean volts.	107.0
" amperes.	7.13
Time.	7.77
Calc. watt hrs.	5926
Obs. " "	5450

η = 91.9 %

3/4 Load (2.)

Mean volts.	107.0
" amperes.	7.13
Time.	9.81
Calc. watt hrs.	6870
Obs " "	7483.

η = 91.8 %

1/2 Load. (1.)

Mean Volts.	107.8
Mean Amperes.	4.65
Time.	8.25
Calc. watt-hrs.	4133
Obs. " "	3760

η = 90.9 %

1/2 Load. (2.)

Mean volts.	107.8.
Mean amperes.	4.65
Time.	6.55
Calc. watt-hrs	3281
Obs. " "	2980

η = 90.8 %

1/4 Load.

Mean volts.	109.7
Mean amperes.	2.62
Time.	7.33
Calc. watt-hrs.	2109.
Obs. " "	1860

η = 88.2 %

Thomson Meter #5114. direct current. Approximately 90 volts.

Full load.

Mean volts.	87.5
" amperes,	9.87
Time.	6.17
Calc. watt-hrs	5333
Obs. " "	5030

η = 94.3 %.

3/4 Load.

Mean volts.	89.0
" amperes,	6.82
Time.	7.58
Calc. watt-hrs	4603
Obs. " "	4380

η = 95.2 %.

1/2 Load.

Mean volts.	89.7
" amperes,	4.93
Time.	7.62
Calc. watt-hrs.	3368.
Obs. " "	3140.

$\eta =$ 93.2 %

1/4 Load.

Mean volts.	89.0
" amperes	2.55
Time.	13.7
Calc. watt-hrs.	3109.
Obs. " "	3010.

$\eta =$ 96.8

<u>Note</u>. In the above, the voltage may be in error in certain cases owing to the fact that the same voltmeter could not be used in all the

tests, but any one which could be obtained. The corrections were not always known and they were somewhat variable.

The time deviation is negligible in all cases, and it is believed that the current is correct in all cases to at least .3 %. The runs were in all cases made long enough to render the error of reading the meter not more than .3 %.

Conclusions

It would seem from the above tests that in running on a 110 volt circuit meter #5114 runs practically 10 %. too slow, and that on a 90 volt circuit that it runs about 6 % slow. The reason for its running faster proportionally at 90 than at 110 volts is not apparent.

It is quite possible that the irregular values of η observed at the same load may be caused in part by variable friction among the wheels of the registering train.

Precision of the Foregoing tests.

Precision of voltage.—Assuming the voltmeter corrections to be correct as given.

A run of 7 hours was made with voltmeter readings taken every 5 min. the ad = .25 volts, and the AD = .05 volt. There were made during the day several sets of readings of 5 minutes duration and 1/4 min. apart. the <u>ad</u> of no one of these with respect to the mean of the days run was greater than .3 volt. and its own AD = .1 volt. We may thus call $\delta v = .1$ volts.

The <u>currents</u> of large volume which were used were measured by a Thomson Current Galvanometer #205 calibrated by a new Weston ammeter (#438). The calibration checked at the close of the series of experiments very well. The errors of reading and the fluctuations cannot cause an error of more the .05 amperes it would seem

$\delta C = .05$

Call $\delta t = \frac{1}{2}$ min. at the utmost

$\delta t = .01$ hour.

Call the error in reading the meter 10 watt hrs. ∴

$\delta M = 10.$

Application to a full load test. $C = 10$ amperes. $\delta C = .05$

$t = 7$ hours $\delta t = .01$

$v = 110$ volts. $\delta v = .1$

Solving by combined effects.

$$\Delta^2 = \left(\delta V \cdot \frac{dE}{dV}\right)^2 + \left(\delta C \cdot \frac{dE}{dC}\right)^2 + \left(\delta t \cdot \frac{dE}{dt}\right)^2$$

E = watt-hours = CVt.

$$\Delta^2 = (.1 \times Ct)^2 + (.05\, Vt)^2 + (.01\, VC)^2$$

$$\Delta^2 = (.1 \times 10 \times 7)^2 + (.05 \times 110 \times 7)^2 + (.01 \times 110 \times 10)^2$$

$$\Delta^2 = 7^2 + (38.5)^2 + 11^2$$

$$\Delta^2 = (49 + 1450. + 121) = 1610$$

$$\Delta = 40 \text{ watt-hours.}$$

$$\Delta_\eta = \frac{40}{7700} = .006$$

$\therefore$ The values of η are reliable to .6 %.

Direct current tests on T.H. meter #7971 (a later type.)

Full load at 110 volts approximately.

Mean volts.	107.4
" amperes.	12.40
Time.	2.67
Calc. watt-hrs.	3551.
Obs. " "	3360

η = 94.6 %

Full load at 90 volts.

Mean volts.	91.1
" amperes.	10.46
Time.	3.80
Calc. watt-hrs	3621
Obs. " "	3470

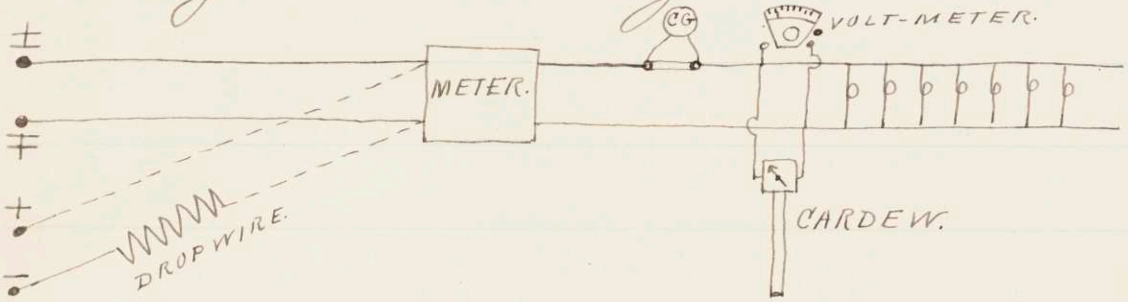
η = 95.8 %

Note. Both of the above tests are believed to be accurate to .3 %. Volt. & ammeter readings were taken every five minutes throughout, but this was shown to be unnecessary. Owing to lack of time there were no tests made upon this meter except at full load but the curves of proportionality of speed to current (shown later) make it fair to suppose that its behavior would have been similar to that of meter #5114.

Conclusions. It is believed that meter #7971 runs about 5 %. slow when running at 110 volts and somewhat less slowly when on a 90 volt circuit, thus behaving as did #5114. It is a much more accurate meter than #5114 for use on a direct current lamp load.

Alternate current tests on the Thomson Meter.

Method:— The meter was loaded with lamps to the desired amount and a Cardew voltmeter arranged so as to be connected across the lamp terminals. The indications of this instrument were taken every 5 minutes during the tests and the average reading obtained.



then after the final reading of the meter and the time of stopping the test had been obtained, the alternating current was switched off and the direct current switched on.

By means of the drop wire, the direct voltage was so adjusted so as to reproduce the mean Cardew deflection which the alternating current had produced. The direct current ammeter and voltmeter were then connected and the current and voltage carefully determined. The product of this direct current and voltage with the time in hours was taken as the "calculated watt-hours".

Alternating current test on #5114 at full load.

Mean volts.	102.2
" amperes.	11.63
Time.	5.84
Calc. watt-hrs.	6938.
Obs. " "	6320

η = 91.3 %

Alternating current full load test on #7971.

Mean volts.	101.6
" amperes.	12.38
Time.	3.20
Calc. watt-hrs.	4038.
Obs. " "	3890.

η = 96.3 %.

Conclusions. The two above tests show a higher value of η with the alternating current than with a similar direct current, thus:—

	Alternating η	Direct. η
#5114	91.3	90.0
#7971	96.3	94.6

Note. The same ammeter and voltmeter were used in all four cases.

Precision of the Alternating current tests.

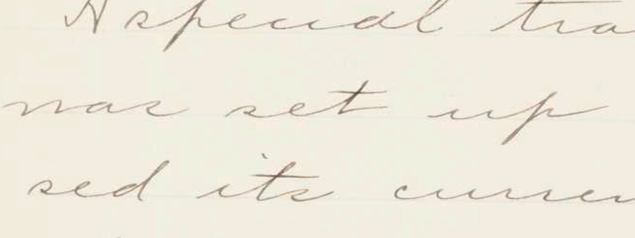
The error involved in this method over and above those in the direct current tests, is that incurred in finding the current. As stated, this was done by subsequently producing a series of Cardew deflections the mean of which should be the same as the mean of the Cardew readings during the test. This was a tedious process but by taking a large number of readings in both series it is believed that a considerable degree of precision was attained.

This certainly would not seem to be natural, and the reason for it is not clear, unless it was due to the lower voltage of the alternating current: 104 volts.

Calorimetric Tests.

It was desired to check the results obtained in the use of the meter on alternating currents, by the calorimetric method.

A special transformer was set up which passed its current through the meter and thence to a german silver spiral in the water calorimeter.



Calorimetric test on #7971 full load of small self induction. at 94 volts.

Mean activity in watts.	1118.4
Time.	4.67
Calc. watt. hrs.	5220.
Obs. " "	5310.

η = 101.7

Voltage about 95.

Note. This value of η may have been due to the combined effect of low voltage, and of an appreciably inductive load, which as will be seen causes the meter to run too fast.

The german silver spiral used in the preceding experiment was provided with an iron core to increase its self induction and a second calorimetric test performed.

Test of #7971 with a considerably inductive load by the calorimeter.

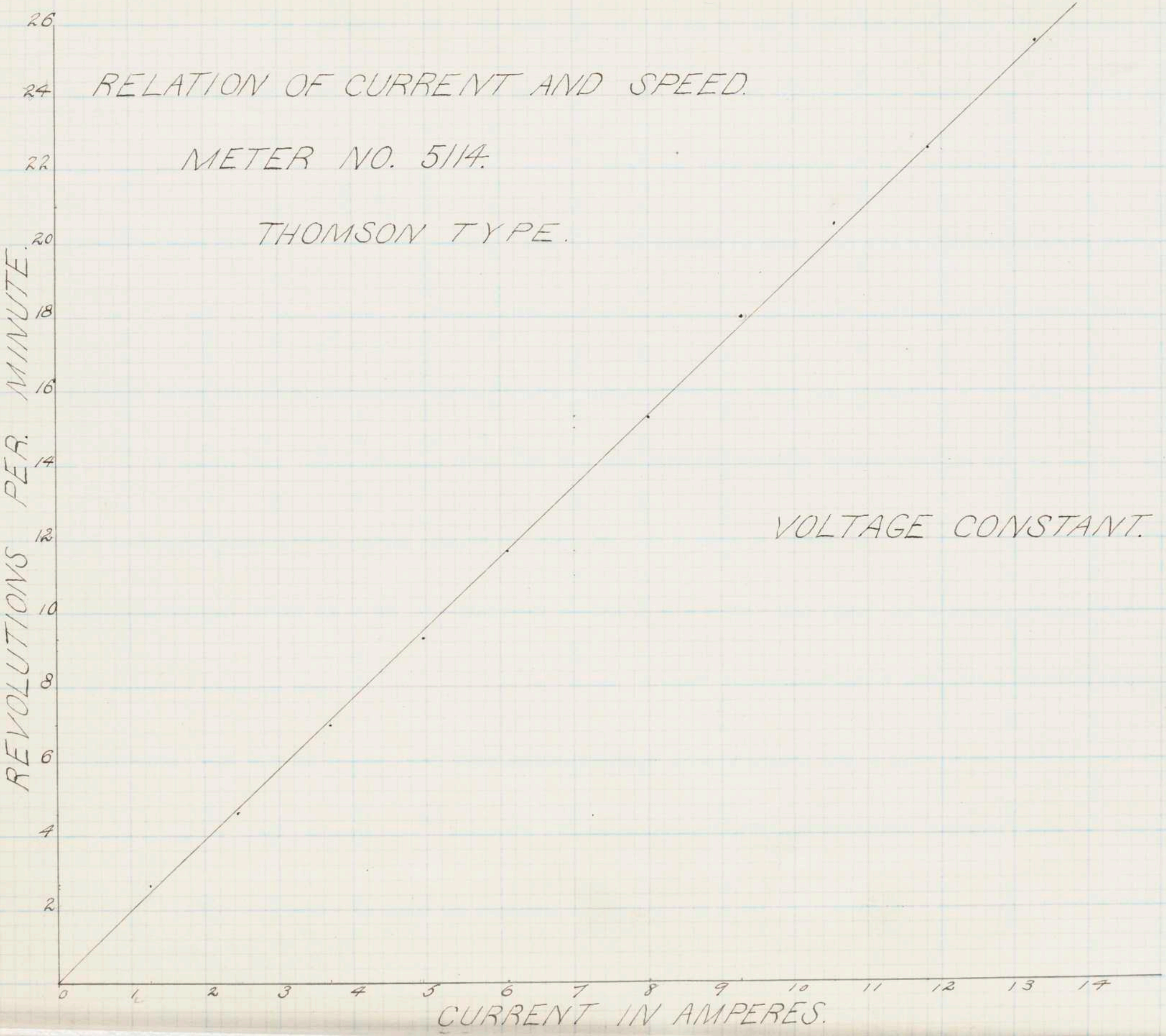
Mean activity in watts.	1148.
Time.	4,88
Calc. watt-hrs.	5605
Obs. " "	5950

$\eta = 106.3\ \%$.

Note. With an increased amount of inductance in the load η increases as noticed more fully later.

Precision of the calorimeter experiments.

The determination of the activity was made at least once each half hour on the average; with a good agreement. The deviation in the time was negligible. The length of the runs was always so proportioned as to give an error due to reading the meter of less than .3 %. The error of the method is increased by the unsteadiness of the alternating voltage, making a larger number of activity tests necessary in order to insure a good mean value, than in the case of a more steady supply.

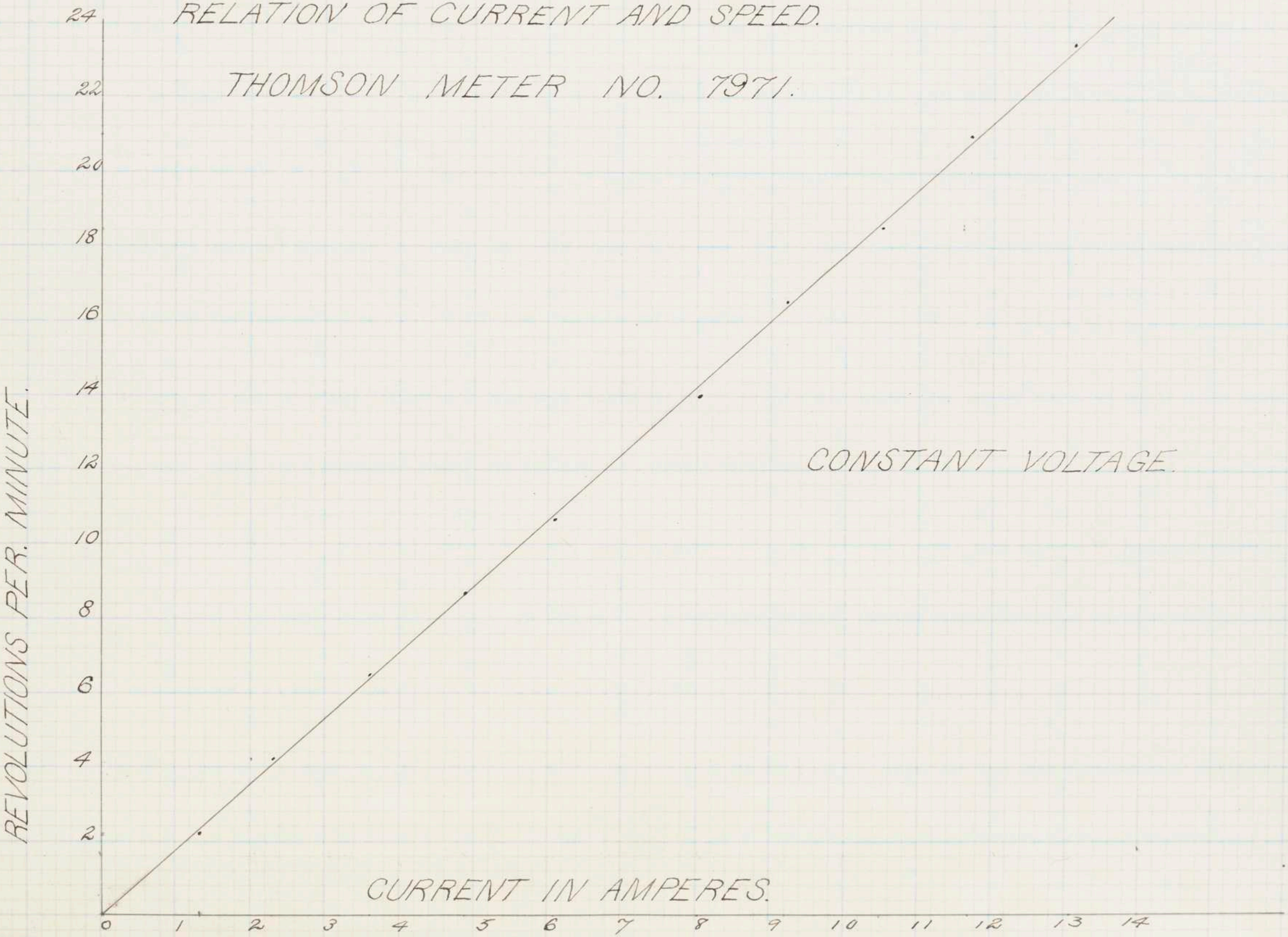

RELATION OF CURRENT AND SPEED.
METER NO. 5114.
THOMSON TYPE.
VOLTAGE CONSTANT.
REVOLUTIONS PER. MINUTE.
2
4
6
8
10
12
14
16
18
20
22
24
26
CURRENT IN AMPERES.
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14

In order to show the proportionality of current & speed of the meter when a constant voltage was maintained, simultaneous determinations of current and revolutions per minute were obtained with the following result.
Meter #5114 at 110 volts direct current.

Current in amperes.		Revs. per. min.
13.18		25.50
11.76		22.50.
10.53		21.00
9.23		18.00
8.02	(See Plot.)	15.33
6.10		11.67
4.92		9.33
3.65		7.00
2.42		4.65
1.30		2.67

RELATION OF CURRENT AND SPEED.

THOMSON METER NO. 7971.

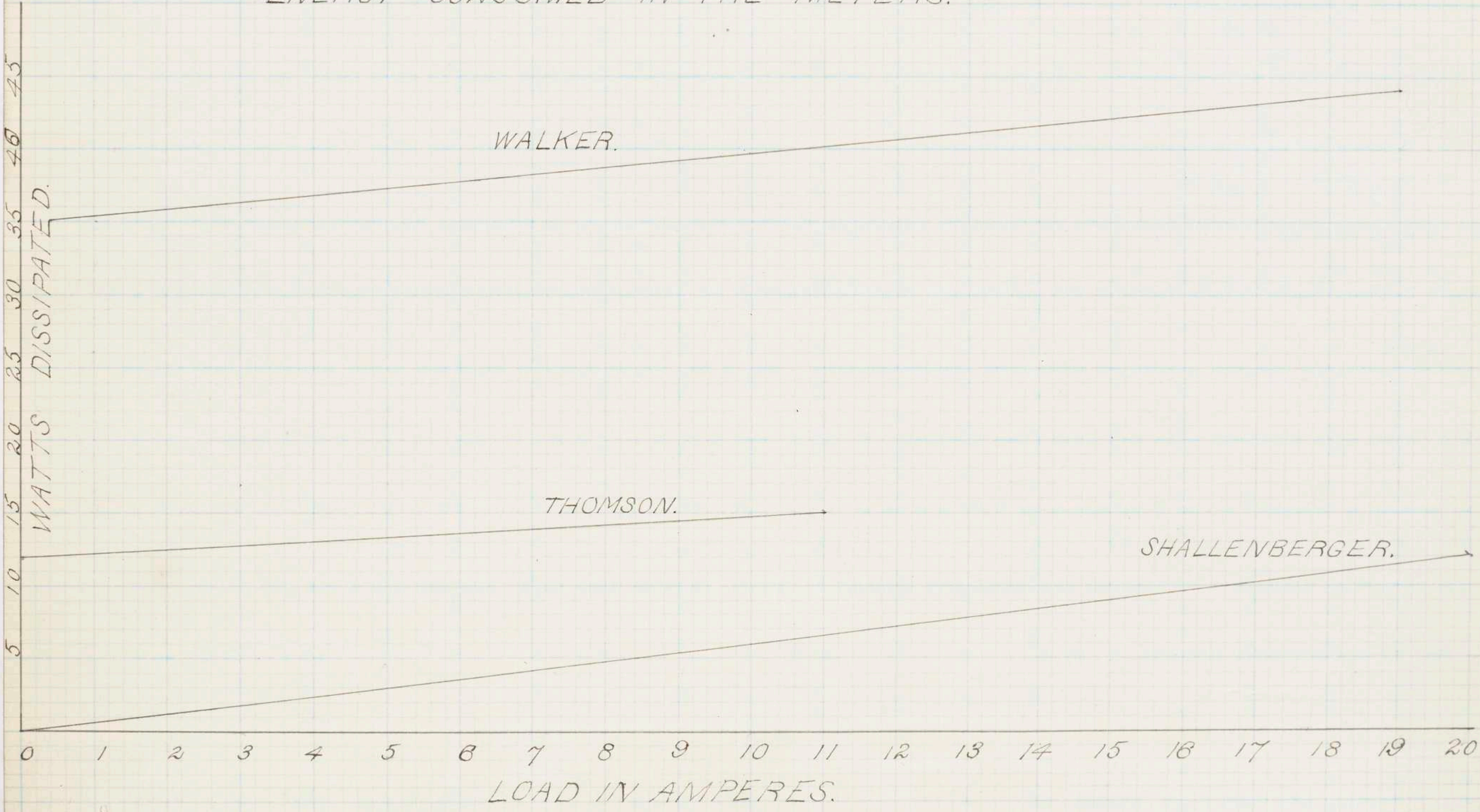


Proportionality of speed and current #7971 at 110 volts.

Current. amperes.	Revs. per. min.
13.18	23.50
11.76	21.00
10.53	18.50
9.23	16.50
8.02 (SEE Plot.p.)	14.00
6.10	10.67
4.92	8.67
3.65	6.50
2.42	4.25
1.30	2.20

It will be seen that the meter show a very beautifully constant proportionality between current and speed, being most excellent in this respect.

ENERGY CONSUMED IN THE METERS.



Energy dissipated in the meter.

To determine this it was only necessary to measure the resistance of the fields (hot) and to determine the current passed by the armature circuit at a certain voltage, the waste of energy is then expressed by $C_{armature} V + C^2_{main} R_{fields}$

The armature current was found to be .11 ampere at 110 volts. and the hot resistance of the fields was .03 ohms. The loss at full load would then be

$.11 \times 110 + \overline{10}^2 \times .03 = 12.1 + 3 = 15.1$ watts

and the percentage loss is

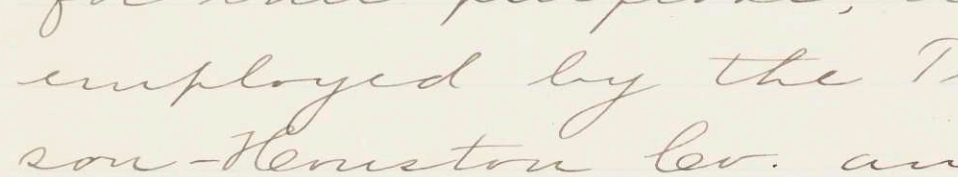
$\frac{15}{1100} = 1.4\ \%$ which is a very trifling loss.

Sensitiveness.— This is all that can be desired and has been spoken of previously. Meter #5114 would run continuously upon a firm support with the current that was passed by 3 110 volt lamps in series connected to the 110 volt circuit. Vibration as has been stated has a marked effect upon the starting of the meter, but has no marked effect after the meter is started. It was conjectured that the increased values of η obtained by the abternating current might be due to the decrease of pivot friction occasioned by the very perceptible vibrations produced by the current. This view is not tenable however for vibrations produced mechanically had no such effect.

Use of the Thomson Watt Meter for testing converters.

An attempt was made to make use of the two meters to check certain converter efficiencies which had been obtained by the calorimetric method.

The mode of using them for this purpose, is one employed by the Thomson-Houston Co. and is as follows:—



The primaries of two similar converters are joined. The secondary of one is connected through a meter with the low pressure mains and the secondary of the other is connected through another meter to a lamp load. Then the efficiency of one of the transformers is given by the expression $\epsilon = \sqrt{\frac{M_2}{M_1}}$ where M_1 & M_2 are the watt-hrs. recorded by meters M_1 & M_2 respectively.

Two 40 light converters were connected as above. Meter #7971 was used to measure the input and meter #5114 the output.

Watt hrs. input by #7971 = 3550
" " output " #5114 3020
then

$$\epsilon = \sqrt{\frac{3020}{3550}} = 92.8\ \%$$

The meters were then interchanged in position. meter #5114 measuring the input and #7971 the output. The following results were obtained.

Watt-hrs input by #5114 2270
" " output " #7971 1750

$$\epsilon = \sqrt{\frac{1750}{2270}} = 88\%.$$

The result obtained as the efficiency of these transformers by the extremely reliable calorimetric method was 93 %. about.

In both cases in which this watt-meter method was tried the efficiency was found smaller than it should have been. This is undoubtedly due to the fact that the meter measuring the input records too much energy, because it is measuring watts furnished to a load which is possessed of high self induction. That the meters record too much under these circumstances. will be shown later

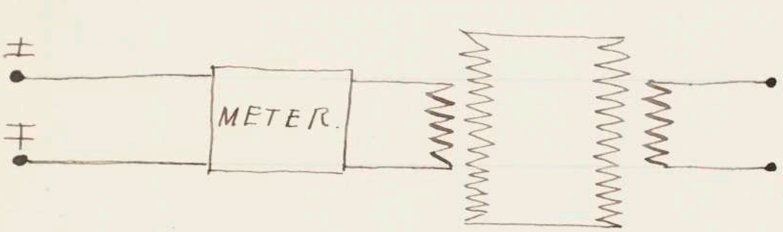
It is not believed that this method is a suitable one unless the meters have been carefully tested; one of them which is to be used for the input, upon an inductive load, and the other which is to be used as the output meter, upon a lamp load.

As a commercial test upon a type of transformer, the efficiency of which is known by some more refined method it would seem to be eminently useful as it is so easily performed.

By its application to all the transformers of a certain size, running at a certain load, which are sent out; it would prove an excellent means for the detection of faulty ones.

Test of the Watt-Meter on a Highly inductive load.

In order to show that the watt-meter recorded too fast when working upon a highly inductive load the following experiment was tried.



The primaries of the two 40 light converters were joined. The 104 volt alternating mains were connected through meter #5114 to the secondary of one of them. The secondary of the other was left open. The energy furnished the system is composed of first. The open circuit loss in two 40 light converters and (2) the heat loss due to the current in the secondary of one of them. This latter quantity is very small indeed, and may be neglected without serious error, or it may approximately be allowed for. The loss in a transformer of this type with its secondary open is known to be 58 watts.

The system arranged as described was started at a noted time and allowed to run for quite a period The time of stopping was then noted and the watt-hours recorded were read; which quantity should equal the product of the time in hours into twice 58 watts. plus the C^2R of one secondary.

Test #1 with meter #5114

Watt-hrs recorded	310
Time in hours.	1.92
Voltage (approx.)	105.

Resistance of one secondary (approx) .06 ohms.

Assumed open circuit loss in both transformers = $2 \times 58 = 116$ watts.

Heat loss in one secondary = $\left(\frac{310}{202}\right)^2 \cdot .06$ = ,14 watts which we will neglect. The calculated watt hours supplied are.

$2 \times 1.92 \times 58 = 223$ watt-hours

$$\eta = \frac{310}{223} = 1,38$$

Test #2 Meter #7971

Watt-hrs recorded	420
Time in hours.	2.5
Calc watt hrs.	290.

$\eta = 1,44$

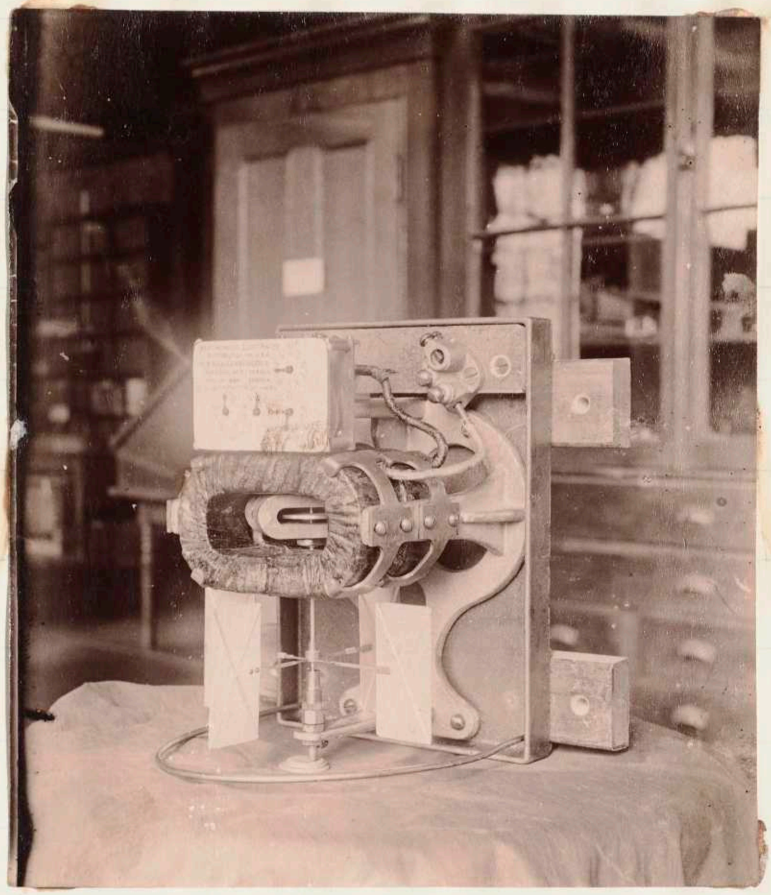
Conclusions.

These two experiments seem to show that the meters do not record correctly on highly inductive loads. The reason is not yet quite clear but it is presumably due to the differen ence of phase of the armature and field currents. And it is also to be noticed that at light loads there is a composite field produced, due to the armature current circulating in the field coils as well as the field current proper. The armature and field currents together, being out of phase produce a very complicated action. This would not be so noticeable at full load probably, as then the field produced by the armature current is a very small part of the total field.

Setting aside however the question of the effect of the armature current in the field let us consider the action. When measureing the alternating energy supplied to a non-inductive load, the armature current probably lags behind the field current owing to the armature's greater self-induction; and less energy is recorded than if both currents were in phase.

When however inductance is added to the main circuit until its inductance is equal to that of the armature circuit the meter will be running its fastest owing to the consonance of the currents within it, and will not be taking account of the decreased energy in the main circuit, as evinced by the lag. That is; it will be running too fast.

At some one point intermediate between these two cases the meter will be correct.



The Shallenberger Meter

The Shallenberger Meter.

This is a meter of the integrating motor type and reads directly to ampere-hours. It is of a very neat form. is very easily installed, is not over delicate and does not contain any moving electrical contacts which would seem to be quite an advantage.

It is intended for use on the alternating system alone and is not operable by continuous currents. As it is intended for use on circuits of the Westinghouse system it may not have been quite fair to operate it by a current of a different frequency. i.e the Thomson-Houston current.

It is virtually a modified Tesla motor which runs an integrating train and a suitable damping arrangement which reduces the speed to the required value. It consists of two parallel rectangular coils in a vertical plane made of coarse wire and carrying the main current; within these are two smaller coils, the circuits of which are closed on themselves. these coils are parallel and in a vertical plane displaced by an angle of 45° in advance of the former coils. Inside of the latter coils rotates a horizontal iron disc on a vertical shaft which carries at its top a worm which drives the registering train. Below the coils the shaft bears a set of aluminum fans which forms the retarding device. The shaft is carefully jewelled

In the operation of the meter, the outside coils act inductively upon the inside ones, producing in them a current displaced in phase, There is a complex field produced by these two currents having a polar line which shifts continuously in direction. The iron disc tends to keep up with this changing direction of magnetism and it does so the more nearly as the field is stronger.

There is no friction reducing device in this meter as in the preceding one.

The tests were made at various loads by the same method as used in the alternating current tests on the Thomson meter.

Test on Shallenberger meter#
Full load.

Mean current	19.35
Time in hours.	3.52
Ampere hrs. recorded.	67
" " calculated.	68

η = 98.5 %.

3/4 load.

Mean current.	15.71
Time.	6.08
Ampere hrs. recorded.	95.0
" " calculated	95.6

η = 99.4 %.

1/2 load.

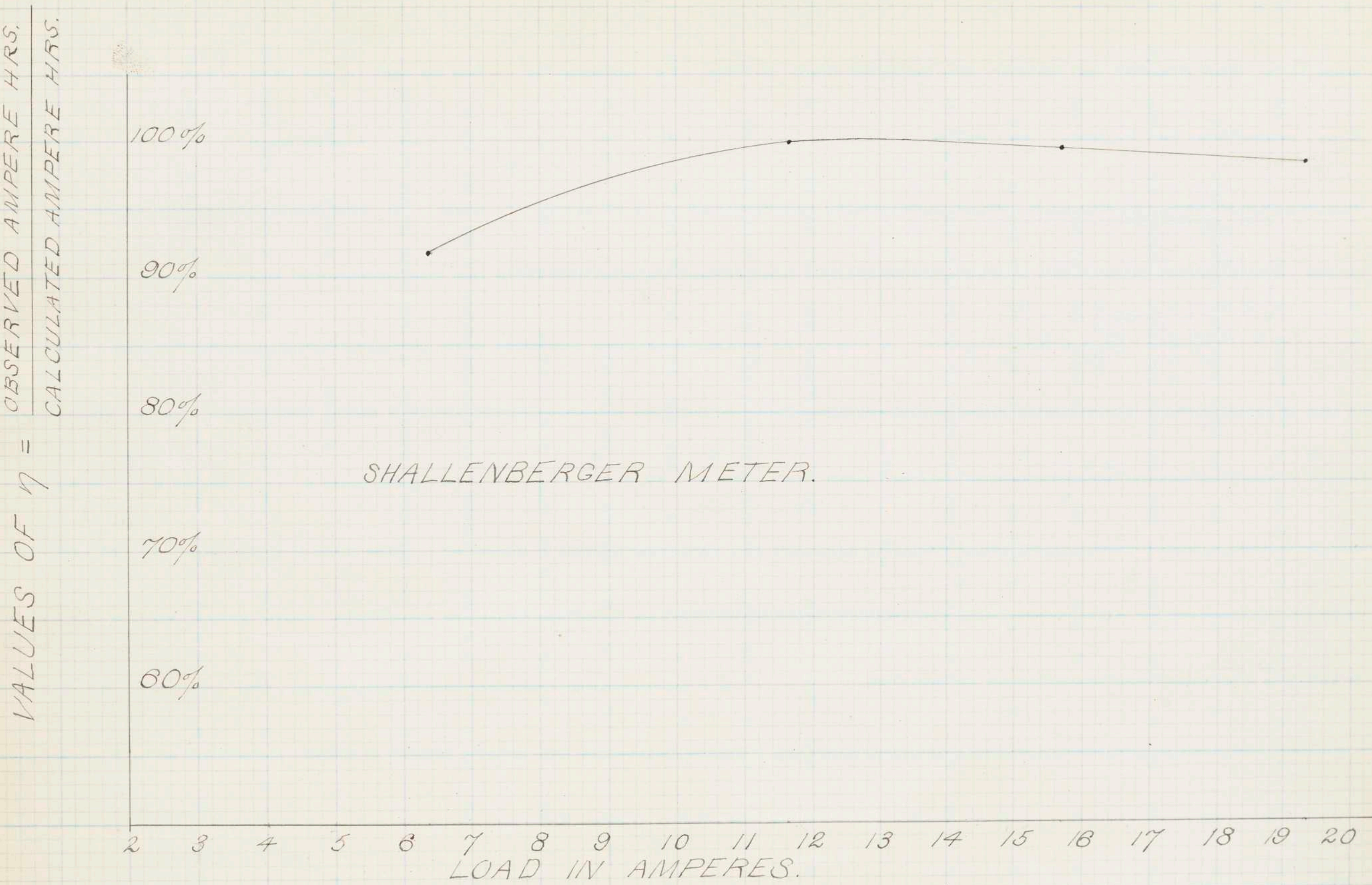
Mean current.	11.63
Time.	5.84
Ampere hrs. recorded.	68
" " calculated	67.9

η = 100.0 %.

1/4 Load.

Mean current	6.38
Time.	7.70
Ampere hrs. recorded	45
" " calculated	49.1

η = 91.7 %.


SHALLENBERGER METER.

Sensitiveness of the Shallenberger meter.

It was found that when the current was increased to about .7 amperes the meter would start and continuously rotate. If the current was decreased to a little below this point the meter would stop.

During the experiment the fans were carefully protected from air currents and the meter was placed on a rigid support. Doubtless it would have started at a somewhat less current if it had been subjected to vibration.

Conclusion. It is seen that the meter will record the current given to one lamp such as are used on the Westinghouse system, as each one of them takes 1 ampere of current.

Energy dissipated in the meter.

This was obtained by taking two sets of Cardew voltmeter readings; one set across the mains after passing the meter and one set across the mains before passing the meter. The difference of the means of these two sets gives the drop in volts due to the meter. The following results were obtained.

(over.)

Drop at 1/2 load .3 volt.
" " full " .6 "

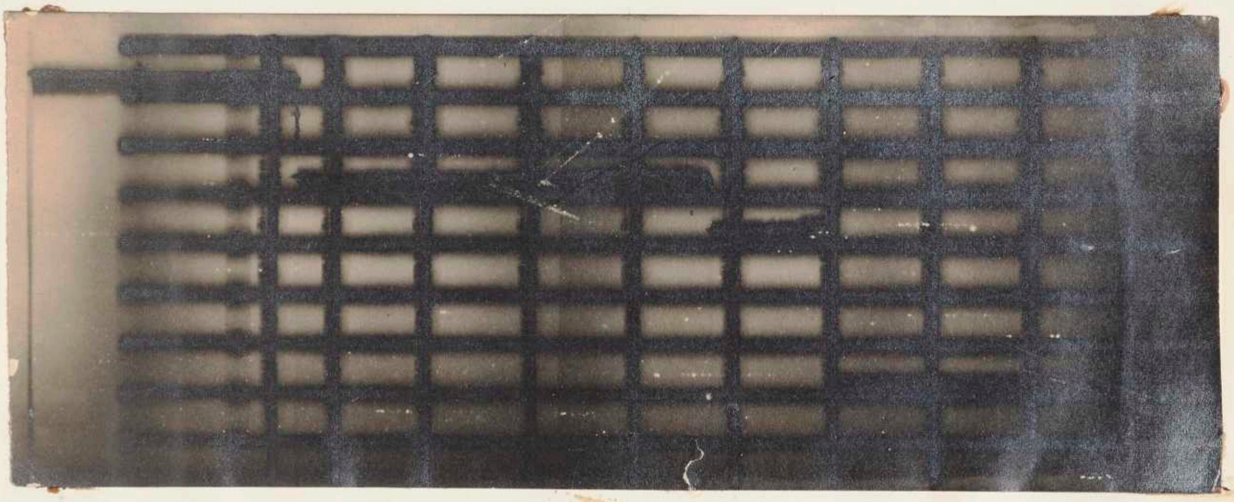
Thus the maximum per.cent loss in this meter is

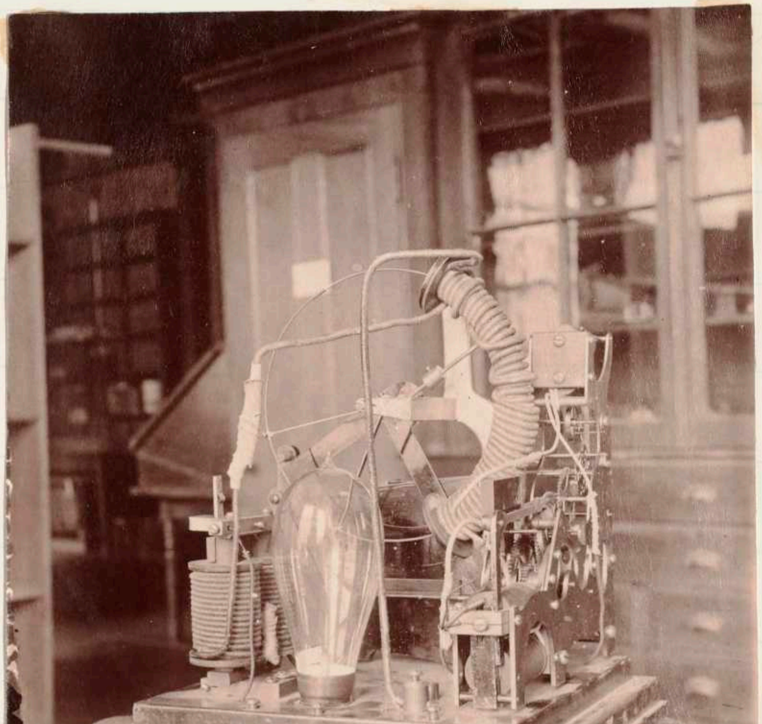
$\frac{.6}{50} = 1.2\ \%$ which seems rather large.

See plot opp. p. 47.

70

The Walker meter.





The Walker meter.

The Walker meter is a recording ammeter which furnishes a continuous graphical representation of the current strength.

The method of obtaining this record is by continuously photographing the deflections of an ammeter placed in one of the mains of the circuit In order that this may be done, the ammeter (which is one of the solenoid type) determines the position of a shutter which admits light through a fine aperture to a piece of sensitive paper uniformly moved along by clockwork. The paper is drawn along in a vertical plane over suitable rollers in a light-tight box having a horizontal slit in its front, past which the quadrantal shaped shutter carried by the ammeter core is made to slide. This has a fine slit in it, the position of which horizontally is proportional to the current. In series with the solenoid of the ammeter is a coarsely wound relay magnet, which, when energized, completes connections that cause the clockwork to start, and light an incandescent lamp within the meter which furnishes the light necessary for the photographing of the position of the ammeter needle.

One of the wheels of the clock work train carries a cam which periodically causes connections to be made to energize a magnet that automatically winds the spring.

By another cam on another shaft a shutter is opened once each hour which allows the light to imprint a straight line across the paper strip which serves to mark divisions of time. Longitudinal lines are also imprinted upon the paper which correspond to its calibrations.

In the practical use of this meter, the box containing the paper is taken off once a month and another one substituted. The box is then opened in yellow light, the exposed paper cut off, and developed and fixed in the usual manner. The area representing the ampere hours of service may best be obtained by means of the planimeter, but may of course be measured without it.

Test on the Walker meter.

The meter was run under various loads, the duration and current of each test being noted. The record was then developed and the ampere hours recorded were ascertained.

No test.	Ampere hrs. recorded.	Ampere hours calculated.
1	14.1	14.8
2	23.7	25.1
3	40.3	35.7
4	42.5	42.5
5	16.8	16.8
6	12.7	13.6
7	50.8	57.0
8	45.6	55.2
	Total = 2465	Total = 2607

$\eta = 94.7$

Note. The accompanying record should be read from left to right. The light used was so intense as to fog some parts of the record. although it was only that produced by a 10 C.P. 110 volt lamp running at about 85 volts.

It is thought that the reason of the too small area of the record; is that there was friction between the ammeter quadrant & the box which did not allow the quadrant quite far enough. There could not have been a zero error of any magnitude as the meter was zeroed carefully.

(hot). The loss in this circuit at full load would be $15^2 \times .04 = 9$ watts.
The total loss is then
$35 + 9 = 44$ watts.
The per. cent loss on a 110 volt circuit at full load would be.
$$\frac{44}{1980} = 2.2 \%$$

See plot opp. p. 47.

Sensitiveness.

The meter would start into action upon the lighting of one 16 C.P. 110 volt lamp, and hence it is considered adequately sensitive.

General Conclusions.

Without making any attempt to arrive at any conclusions regarding the relative merits of these three types of meter, attention may be called to certain points concerning them. Most especially to be noticed is the attainment of virtually perfect proportionality between speed and current, and of entirely adequate sensitiveness in the Thomson meter, — results which it is believed have never fully been secured in motor-meters of previous types. On the other hand it is to be remembered that the energy loss in this instrument, although small, is continuous, lasting as long as pressure is applied to the mains to which it is connected, and whether current is flowing or not. Moreover, it certainly does not seem that these meters receive remarkably careful standardization at the factory, if the two tested are fair samples in this respect. That the use of these meters with alternating currents should be confined to non-inductive loads cannot be too strongly emphasized.

and it is a question whether the commutator used, would not after long usage become troublesome.

The simplicity of the Shallenberger meter and its low average energy consumption tend to compensate for its slight inaccuracies at extreme loads; and its sensitiveness (if the meter tested be a fair sample.) is quite tolerable. The fact of its having no moving electrical contact in its mechanism is certainly in its favor.

While it is perhaps desireable to obtain a permanent record of the energy consumed, it does not seem wise to do so at so great a sacrifice of simplicity as in the case of the Walker meter. Its large energy loss, and necessary photographic manipulations make its desireability for general use somewhat doubtful.

The application of this very ingenious instrument, in a central station, to the determination of its rate of output, or as a check to the constancy of its "constant current" or "constant potential" circuits might however be very advantageous.