# REGULATION AND TESTING OF WATTMETERS.

by

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and

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## Preface.

The writers have endeavored in this short treatise to present the subject in a simple, readable form and in as practical a manner as possible, covering briefly the evolution of our present wattmeter system and the underlying principles of the instruments together with a few laboratory tests and our conclusions.

While this treatise is not claimed to be exhaustive, still as impartial authorities who have written upon the subject in other than a strictly mathematical way are not numerous, we hope that it may at least prove to be an interesting addition to the small amount of literature on the subject.

Use has been made of the bulletins on wattmeters issued by the various manufacturing companies wherein much reliable and useful information could be obtained that was not available from any other source.

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The business of electric lighting and power distribution from central stations has grown to such a volume that millions of dollars change hands yearly in the transaction of that business. The commodity exchanged is the electric current and yet there is great uncertainty as to what that so called current really is. Considering this fact, the enormity of the business built upon this invisible something is rather surprising.

The general lack of definite knowledge on the subject and the fact that the commodity is intangible are perhaps responsible for the laxity that has existed in the buying and selling of electrical power until a comparatively recent time. The sale of current involving large sums is often based upon measurements taken with poor, inefficient instruments or upon a system of calculation closely allied with guessing. Such a manner of doing business would have resulted in bankruptcy in any other line, but the spirit of the age has entered the trade and the cry for the past few years has been for a more accurate system and this means better instruments. While the station manager knows that his financial success depends largely upon the excellence and efficiency of his plant yet he cannot shut his eyes to the fact that his income depends largely upon the system by which he sells his current. Dissatisfied or suspicious customers are not conducive to prosperous trade, and dissatisfied or suspicious they will be if they feel that there is inaccuracy or guessing in their accounts. The effect of poor measuring devices usually reacts in two ways upon the central station manager for beside trouble with customers he also has to stand a loss from inefficient metering, this loss often amounting to eight per cent of the current going through the meters. With the rapid strides of electrical enterprise, however, the improvement and manufacture of electric meters has in a large measure kept pace and today there are on the market a number of very efficient meters.

The first patent on electric meters issued by the United States was dated October 29, 1872 and was issued to S. Gardiner Jr. The next was issued November 26, 1878 to J. B. Fuller on what was perhaps the first alternating current meter made. Up to 1891 the patent records show that 185 patents were issued. There were a great number of very ingenious devices but their cost of manufacture and ease of derangement kept the most of them out of the race from a practical standpoint. It is only about fifteen years since the meter system came into use in any form and only about twelve years since the motor type as we now have it was adopted.

The first meter that attained any degree of success in a commercial way was the Edison Chemical Meter patented in 1881. The principal claim for this meter was an electrolytic cell placed in shunt with the current to be measured and so regulated by a resistance that only a small proportional part of the current went through the meter. The chemical action consisted in the deposition of metal from one electrode to another upon the principle of the voltameter. As used by the Edison Company it was so regulated both in large and in small meters that one milligram of metal deposited represented one ampere hour.

The first successful alternating current meter was the Shallenberger Meter patented in 1888. It is of the well known motor type with revolving coil. The damping effect instead of being accomplished by the more modern device of damping magnets was accomplished by means of wings or vanes but it is a question whether this damping effect varies as the square of the current.

The Aron Meter was a very ingenious contrivance of German origin and ten or fifteen years ago was used quite extensively in Germany but its size and cost were prohibitive to its extensive use in American practice. In this meter the current passed its noted by the difference in movement of two thirty-day clocks whose pendulums, when no current is passing, swing synchronously. One of the pendulums has a steel magnet at the end which is influenced by a coil just below it through which the current passes. As more current flows through the coil the magnetic pendulum swings faster, and from the difference in time indicated by the two clocks at the end of the month the current used was calculated.

One of the best known if not the best known meter of today is the Thompson Meter. The present day type of his meter will be described in detail a little later, but at this point it might be of interest to mention Mr. Thompson's first form of meter. It was a so called "vapor neter," the principle upon which it worked being vaporization of ether, alcohol or glycerine in two sealed glass bulbs connected by tubes. In either of these bulbs was a very thin platinum foil or wire to which the terminals of shunt wires from the main circuit were connected. The tubes connecting the bulbs were intercepted by a small reservoir filled with a heavy liquid and the whole pivoted so that the bulbs could alternately rise and fall. When the platimum foil in one of the bulbs was heated by the passage of a current it expanded the gas in that bulb which in turn forced a portion of the heavy liquid in the reservoir over into the other bulb; this destroyed the equilibrium and caused the bulb to sink. This sinking caused a connection of the foil in that bulb with the terminals of the shunt at the same time breaking connections on the other end. Bulb number two was then heated and the operation reversed thus causing oscillations of the beam. These oscillations were registered and from that the current measured or calculated. The scheme may have been ingenious but it did not appeal to the public in a commercial way.

Thompson's motor type was almost exactly the same when it first came out as it is now and that form is familiar to every one experienced in station work. Perhaps the greatest change he has made is the substitution of brass or alloy for the frame in place of iron. The iron frame had the effect of creating an auxiliary field thus destroying the accuracy of the meter.

Another meter deserves mention in this synopsis if for no other reason than its novelty. This is ths Walker Meter invented in 1889. Here a record was kept on a roll of sensitized paper that was revolved by clockwork. A small incandescent lamp on the inside of the meter supplied the light when any external current was flowing. A ray of light from this lamp was admitted to the roll of paper through a slit or hole in the end of an ammeter needle, an arrangement also being made for marking the hours. Each month this roll was taken out, developed and integrated. It needs no exposition to show how many things might happen to a meter like this.

Mr. Weston in 1883-84 took out patents on meters very similar to the Thompson Meters and several practically new meters are on the market. Among these latter the Gutmann and the Stanley meters are notable examples. They are both induction meters, small and compact and are fast becoming popular.

A theory that was made much of during this spring time of the wattmeter system was the necessity of a visible dial for the customer's benefit. It was urged that he knows that he pays so much for so many things and if there is a dial that he can read the consumer will be better satisfied. It may register lamp hours or horse power, it is all the same to the consumer. However it may be, I think that the idea was given too much prominence but as it is, general convenience has firmly established the use of a visible dial.

Present use demands a meter that is easily adjusted, light, compact, not too costly, but above all as accurate as possible. It must withstand such disturbances as vibrations (to a limited extent of course) of the meter support, variations in voltage, short circuits sufficient to blow fuses in the meter circuit, change of temperature etc. and at the same time perform accurately its function of measurement with small consumption of power.

In the average small station the meter is put to its severest test for here there is usually a dirth of instruments and those on hand and even the switch-board instruments are frequently so antique, or have seen so many accidents due to unskilled attendance that they are quite often very inaccurate and the idea of keeping two or three good standards to check up by, the average station manager will not entertain for a moment. The consequence is that the voltage varies widely on different lines and normal conditions are strangers. Quite often it may occur that when the station instruments are connected to the secondaries of an old transformer and the machines regulated accordingly, while out on the line at some point where there is a new and more efficient transformer installed the voltage may be far from normal. One instance that came under the author's observation was such a case as this. The normal voltage was 104 but testing with a new standard voltmeter across the main switch in a house having about twenty lights showed a voltage under working conditions that varied from 113 to 117. It is under conditions like these that a meter must operate and in addition is never tested in hundreds of cases until a short circuit or a stroke of lightning burns out some of the coils. Such a state of affairs is not only unbusinesslike but is detrimental to the trade. Confidence in a plant where such loose methods prevail, whether the benefit falls to the station or to the consumer, requires some effort.

In the installation and use of meters it is a question of no small moment to the station manager whether to install a small number of large meters or a large number of small meters. It is a question requiring judicious consideration and governed largely by circumstances. The small meters have a larger number of turns in the series coils and hence the loss in the meter is proportionally greater but on the other hand the meter of large capacity that will register as accurately on small loads as on heavy ones is yet to come before the public. In the common example of residence lighting the greater part of the current used is very frequently consumed by only a very few lights at a time even though the maximum load is high. In a case like this if the maximum load would warrant it, it would be manifestly better to install two meters whose combined capacities would carry the maximum load of lights and would yet register accurately one or two lights, but in a case where a heavy load was on all the time one large capacity meter would be better and cheaper than two or more small ones.

In the following pages we have taken up the individual discussion of a few of the more prominent meters in use today, and have endeavored to explain as simply as possible the underlying principles of their operation and give the results of a few tests.

## The Dynamometer.

If we have two incandescent lamps of exactly the same construction, one fed by an alternating and one by a continuous current until they reach precisely the same state of incandescense, the effective strength of the alternating current would obiviously be equal to that of the continuous current. Since both lamps have the same temperature their resistances must be equal: Let "R" be the resistance of each.

Then the work done in the time "T" by the direct current is equal to EIT. or $= I_o^2RT$ if $I_o$=strength of continuous current.

Work done by alternating current $= \int_0^T I^2 R dt$

where-

I= instantaneous value of current, which is a function of the time "t"; This function being graphically represented by the current curve which may be of any form.

The effective value of the alternating current is--$I_o = \sqrt{\frac{I}{T}\int_0^T I^2 dt}$.

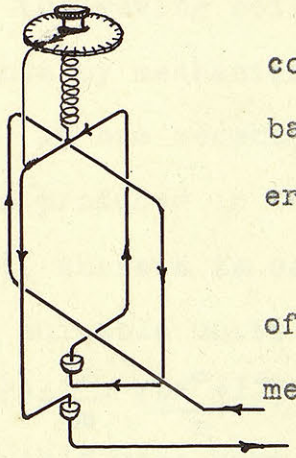
Now will the ammeter show this, or some other value? All instruments used for measuring alternating currents are based upon some electro-dynamic, or some heat effect of the current.

In either case the momentary action produced is proportional to the square of the momentary value of the current-- and all these instruments will be equivalent.

We may then restrict the discussion to one particular type of instrument. The Weber Dynamometer is representative and will be considered.

The general appearance in outline is shown in the figure where a fixed coil or two fixed coils, if a varied range is desired, is mounted upon a vertical support. Within this fixed coil a movable coil is delicately suspended by means of a thin spiral spring, from a torsion head, the lower extremities of the suspended coil terminate in two cups of mercury to afford convenient connection.

The torsion head has degrees stamped upon the outer edge if its disc, as shown, and a pointer, rigidly attached to the movable coil plays about the circumference of this disc.



For measuring currents the two coils are connected in series and the torsion head turned back to oppose the current's action until the pointer registers zero.

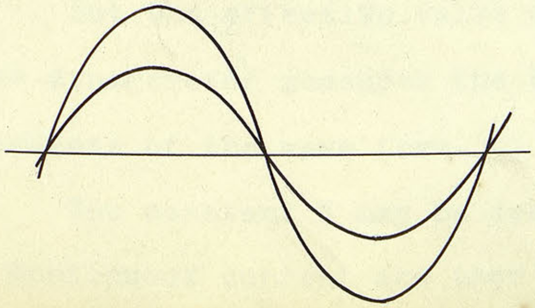
A reading is then taken and the square root of this multiplied by the constant of the instrument gives the current value. $I_0 = K\sqrt{D}$

The current is then directly proportioned to the square root of the angle of torsion. For example, if with one current the number of degrees noted was (36) and with another current (144), then the currents are to each other as $\frac{\sqrt{36}}{\sqrt{144}}$ or $\frac{6}{12}$ or $\frac{1}{2}$.

Now returning to the theory--In the case of a continuous current $I_0$ the deflecting force $D = I^2\frac{1}{K^2}$ where "K" is a constant depending upon the construction of the instrument or $I_0 = K\sqrt{D}$ as has been said.

The question now to be considered is if this formula is applicable if the current is not continuous, but alternating according to any regular or irregular function of the time.

This function may be, and usually is, represented by a curve whose ordinates are instantaneous current values and obscissae time values.



By squaring the ordinates we obtain a second curve the area of which is-- $\int_0^T I^2 dt$ and this area divided by the base line T gives the square of the effective current value or $I^2 = \frac{1}{T}\int_0^T I^2 dt$

Now if the torsion head be turned to zero when the current is applied then left in that position after the current is turned off it is seen that, if $I_t$ is an instantaneous value of current, the force D acting at this instant is $(DK^2-I_t^2)$

This force produces an acceleration- $(\frac{DK^2-I_t^2}{m})$ where (m) is the mass of the moving coil.

Since by mechanics;-- If (f) is the velocity imparted to a body of mass (m) in one second (acceleration), by a force F; then (mf) is the momentum produced in one second, and F is proportional to (mf); (e.g.) FK= (mf), where K is some constant.

If suitable units are taken this constant becomes unity or F= (mf) hence $(f)= \frac{F}{m}= (\frac{DK^2-I_t^2}{m})$

If this mass were sufficiently small, the acceleration which would be alternately positive and negative, since at different times $(I_t)$ is greater and less than the effective $(I_o)$,- would set up a visible ascillatory movement of the coil, the velocity of which would be $v=\int_o^t \frac{(DK^2-I_t^2}{m}.dt$ since Ft= mv for F= mf hence Ft= mft or Ft= mv

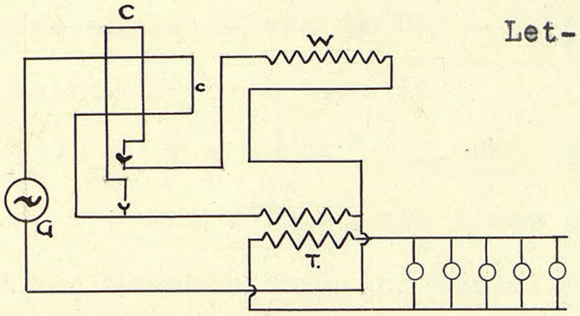
But in the actual instrument the mass (m) of the coil is large compared with the forces acting, also the frequency of change of acceleration from positive to negative is so rapid that no visible movement is observable.

The velocity (v) at all times must be infinately small, or expressed mathematically $\int_o^t (\frac{DK^2-I_t^2}{m})dt = 0$; $\int_o^t DK^2dt-\int_o^t I_t^2dt=0$ or $DK^2\int_o^T dt= \int_o^T I_t^2dt$ hence $DK^2= \frac{I}{T}\int_o^T I_t^2dt.$

But the effective value of current squared$= \frac{I}{T}\int_o^t I_t^2dt$, and hence the dynamometer measures the true effective value of the current regardless of the wave form.

The constant K may be determined once for all by calibration with a continuous current and then may be used to measure alternating currents.

It yet remains to show how the dynamometer can be used to measure power, and to determine whether or not such measurements are accurate for currents of irregular wave shape.



Let- C= movable coil

c= fixed coil

w= non-inductive load

G= alternating generator

T= transformer

The current at which the power to be measured is led through the fixed coil and a shunt containing a non-inductive resistance (w) is placed in series with the movable coil and bridged across the load (primary of T).

If the shunt (w) is very large we have the right to assume, without sensible error, that the current therein is in phase with the E. M. F. impressed; hence the current flowing through the movable coil has no lag and is proportional to the E. M. F.

The current through the series coil may lag or lead according to the nature of the load.

Let- I = the main current

$I_m$ = maximum value of I

i = shunt current

$i_m$ = maximum value of (i)

then if the E. M. F. and current are sine waves, the turning moment acting upon the movable coil is proportional to $I_m \sin(a-\Phi) i_m \sin a$ where (a) is the phase of the E. M. F. at the time to which the expression refers, and $\Phi$ the angle of lag of current in (c), the fixed coil.

If R = resistance of shunt and connexions, then $i_m = \frac{e_m}{R}$ and the turning moment may be considered proportional to $I_m \sin(a-\Phi)\frac{e_m}{R}\sin a$ By twisting the torsion head of the instrument to balance, we must apply a force: $f = DK^2$. The acceleration at the time to which the phase angle refers is $\left(\frac{DK^2 - I_m\frac{e_m}{R}\sin(a-\Phi)\sin a}{m}\right)$ and the velocity attained after a time (t).

$$V = \frac{1}{m}\int_0^t\left(DK^2 - I_m\frac{e_m}{R}\cdot\sin(a-\Phi)\cdot\sin a\right)dt.$$

But V is at all times equal to zero owing to the inertia of the movable coil and rapidity of accelerations. Hence the coil remains at rest and

$$tDK^2 = \int_0^t I_m\frac{e_m}{R}\sin(a-\Phi)\sin a$$

$$\text{or}\quad DK^2 = \frac{I_m e_m}{R}\int_0^{2\pi}\sin(a-\Phi)\sin a\,\frac{da}{2\pi}$$

Solving $DK^2 = \frac{1}{R}\cdot\frac{I_m e_m}{2}\cos\Phi$

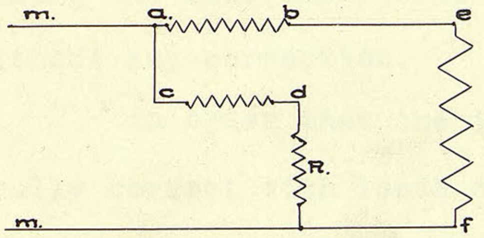
But $I = \frac{I_m}{2}$ and $C = \frac{e_m}{2}$ hence $DK^2 = \frac{I}{R}\cdot\frac{Ie}{1}\cos\Phi$. But $Ie\cos\Phi$ is the power carried by the current I flowing under a potential difference (e) and having a lag $\Phi$.

The product $RDK^2$ is therefore the power of the alternating current.

## THE WESTON INDICATING WATTMETER.

In the Weber dynamometer, the fixed and movable coils are connected in series, hence the torque is proportional to the product of the currents in each, or is proportional to the mean square values of the current.

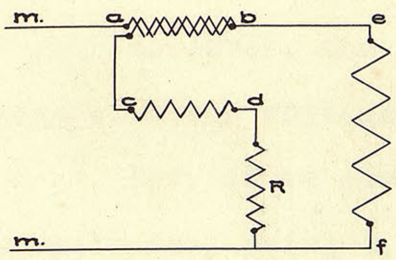
If now instead of connecting thus, we place one coil in the main circuit as we would an ammeter, and the other in series with a high resistance across the load as we would a volt meter, a wattmeter is the result.



In the figure, ab is the series coil which carries the entire current supplied to the load and cd is the coil which in series with the resistance R is connected across the mains (m-m). Now the torque at any instant is proportional to the product of the currents in the coils at that instant.

But the current in the voltage coil is directly proportional to the voltage over the mains, consequently the torque is proportional to (EI) or the product of the instantaneous values of the current and voltage and the deflection multiplied by a constant is the power value, required. Obviously a scale could be easily calibrated to read power directly. This is done on the commercial instruments.

With the voltage terminals connected as shown above, the drop over the current coil ab is added to that over the load ef, thus making the reading too high by an amount equal to the loss in the current coil. But if c be changed to connect at b the current which supplies the voltage coil must all pass through the current coil. This addition to the load current already flowing in that coil produces a reading which is again too high.



The method of compensation is not far to seek. It consists essentially of winding over the series coil, differentially, exactly the same number of turns of fine wire, as occur in the series coil, and connecting this second coil in series with the voltage coil and shunt resistance.

This neutralizes that portion of the field set up in the series coil by the current which supplies the voltage coil, thus making the instrument read the power expended in the circuit without any correction.

In order that the indications of a wattmeter may be practically correct with loads of any character whatever, it is necessary that the self induction of the voltage coil be small as compared with its resistance. To this end the coil should consist of as few turns as possible and be placed in series with a large non-inductive resistance.

With such an arrangement the coil produces only a weak field and to secure sufficient sensitiveness the current coil must have a strong field. To diminish the disturbing effects of foreign currents the coil possessing the weaker field should be the suspended one.

The reasons why a large non inductive resistance is necessary in connection with the shunt coil, will now be considered.

The effect of self induction in the voltage coil is twofold. If the wattmeter has been calibrated with direct currents it will read too low with alternating currents, since with the same terminal voltage, in the two cases the currents in the coil are to each other as 1 : cos $\Phi$, where $\Phi$ is angle of lag in the coil in question.

Moreover, the currents in the voltage coil will not be in phase with the voltage, but will lag behind it.

Now, if we also have an inductive load the angle of lag in the main coil being $\Phi$, the current in the shunt circuit then differs from that in the main circuit by an angle of $(\Phi - \theta)$

The reading of the wattmeter is then proportional to EI cos $(\Phi - \theta)$. Introducing both factors we have wattmeter reading = EI cos $\theta$ cos $(\Phi - \theta)$; and true watts = $\dfrac{\text{Wattmeter reading X cos } \Phi}{\cos\theta \cos(\Phi - \theta)}$ for theoretically true watts = EI ( cos $\Phi$,) the derivation of which is as follows:

Let the accent (') denote instantaneous values. If the current lag by an angle $\Phi$ then -

$E' = E_m \sin a$

where $a = 2\pi ft$

and $I' = I_m \sin (a - \Phi)$

$P' = E'I' = 2 \text{ EI} \sin a \sin (a - \Phi)$

But $\sin (a - \Phi) = \sin a \cos \Phi - \cos a \sin \Phi$

So $2\text{EI} (\sin^2 a \cos \Phi - \sin a \cos a \sin \Phi) = P'$

Remembering that $\Phi$ is a constant, the average power over 180°

$$P = \frac{2 \text{ EI} \cos \Phi}{\pi} \int_0^{\pi} \sin^2 a \, da - \frac{2\text{EI} \sin \Phi}{\pi} \int_0^{\pi} \sin a \cos a \, da$$

$\therefore$ $P = \text{EI} \cos \Phi$ which is the general expression for power in an alternating current circuit.

The instrument gives theoretically correct readings only when there is no relative phase difference of the currents in the two coils at any instant, that is when $\Phi = \theta$ or when $\theta = 0$.

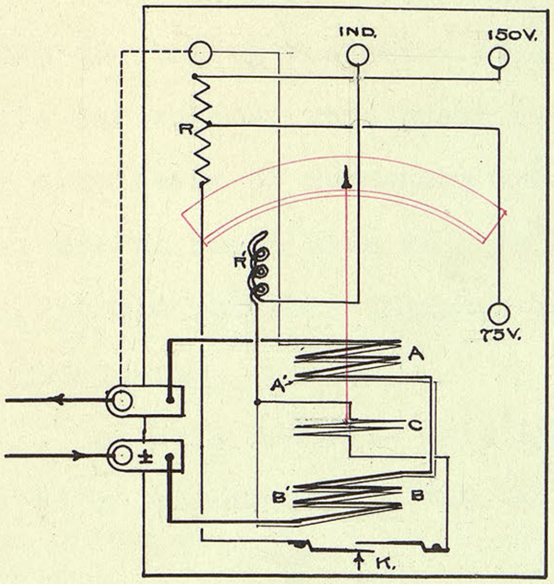
When $\Phi$ is less than $\theta$ the readings are too small, and when $\Phi$ is greater than $\theta$ they are too large. The correction is of greater importance in cases where $\Phi$ is large. This is evident from the formula, since the cosine changes more rapidly as the angle approaches 90°.

Wattmeters are now constructed with the self induction of the voltage circuit less than .004 henry, and with resistances of 1250 Ohms for 75 volt circuits, and 25,000 ohms for 1500 volt circuits. With a frequency of 100 this gives 7 minutes and less than 1/2 minute, respectively, as the values of $\theta$ corresponding to the two resistances above. With a seven minute lag, the correction is eight-tenths of one percent when $\Phi$ is 75°, and two tenths of one percent when $\Phi$ is 45°.

It is seen by the formula for wattmeter reading that as $\theta$ approaches zero the wattmeter reading approaches the true theoretical reading. So in case high non-inductive resistances are used, the correction becomes less.

For all measurements on transformers with closed magnetic circuits, and for most measurements on transformers with open magnetic circuits, such an instrument may be used without any correction. It would not be accurate, however, if used to measure the no load losses of a transformer with open magnetic circuit with the low pressure coil as primary.

The well known Weston Indicating wattmeter is constructed upon the above principles as will readily be seen from the accompanying diagram taken from a late model.



Here the voltage coil c is pivoted delicately between the two series coils A and B each of which has three turns, and over each of which is wound compensating coils A' and B' of three turns each.

The resistances R R' are each non-inductive and are composed of a special alloy, the specific resistance of which remains unaltered by variations in temperature. K is a button, which, when depressed and given a quarter turn, inserts, permanently, the voltage coil in the circuit. A light aluminum needle is rigidly attached to the movable coil.

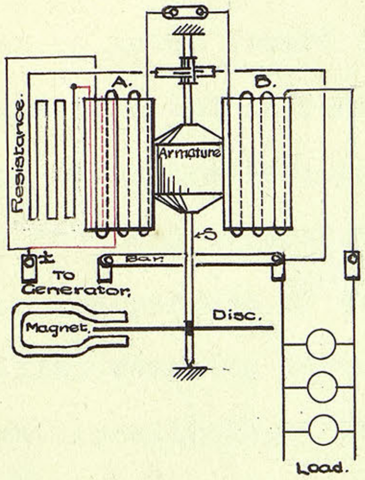
The post marked IND. is the one to be used in connection with either the 150 V. or 75 V. posts when it is desirable to exclude the compensating coil. With direct current and no load the reaction of the movable coil and compensating coil produces a slight negative reading. The earth's magnetism also effects the no load position of the needle to a small extent.

The type of instrument here shown may be used on circuits of either 75 or 150 volts without multipliers by connecting to the proper pressure terminals.

## THE THOMPSON WATTMETER.

If we shpuld supply the moving element of a non-compensated Weston indicating wattmeter with a commutator, so that instead of simple deflection, continuous rotation results; and should we provide some means of governing and recording the number of these rotations we would have in form at least, nothing more nor less than the old reliable Thompson integrating wattmeter so universally used to-day.

So well known is this type of meter that only a brief description is necessary. The two series coils A and B are composed of few turns of very coarse wire, which in meters of higher capacities is of square crossection. The form of this winding is rectangular. These coils are rigidly mounted within a brass frame and the terminals connected as shown, one to the generator, the other to the load. Between these centrally is placed an armature, neatly wound with many turns of fine wire and mounted upon a thin vertical spindle which is supported below by a jewell bearing.



The commutator, which is on the upper end of this spindle, usually has about six or eight that uniform rotation may result. The segments of this commutator are separated simply by thin air spaces, no mica or insulating compound being used.

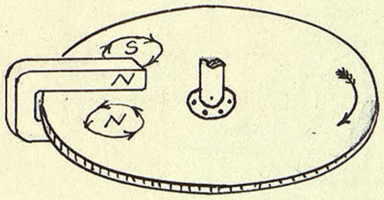
A pair of long, thin, flexible, copper brushes faced with platinum contacts, conveys current to the armature. The tension of these can be varied within a considerable range by means of suitable adjusting nuts.

Still above the commutator there is cut upon the spindle a worm which engages with a small pinion, thus operating the recording train. The lower end of the spindle passes through a copper or aluminum disc, which by means of a set screw against the shaft or spindle, is adjusted to revolve between the poles of one or more horseshoe magnets, the object of which will be explained later. 109

Within the left-hand series coil is placed another coil so that it can be moved toward or away from the armature: this is called the pressure coil and is connected in series with the armature and a large non-inductive resistance, the whole of which is bridged across the load and constitutes the potential circuit. The pressure coil is for the purpose of overcoming constant mechanical losses and giving initial starting torque, thus enabling the instrument to record accurately with light loads. Its position should be such that the armature is just upon the point of rotation at 200 no load. Plainly, to increase the torque the coil is moved toward the armature.

Owing to the fact that in iron, quality, uniformity, magnetic history, etc. enter in, and are constantly subject to variation, the use of iron in the construction of these meters is abstained from.

Suppose now that the instrument above described, which is virtually a shunt motor, be subjected to the action of the current from a generator -- obviously, it would begin to rotate and each rotation would be accelerated until an enormous speed is attained. The function of the disc and magnets above mentioned is to hold this 300 speed within reasonable limits. The action is as follows: --



If a metallic disc be revolved between the poles of a common horse shoe magnet (see figure) eddy currents will be set up within that portion of the disc adjacent to the poles in such a direction as to oppose the motion (Lenz's Law). The amount of this retarding effect is directly proportional to the speed of rotation.

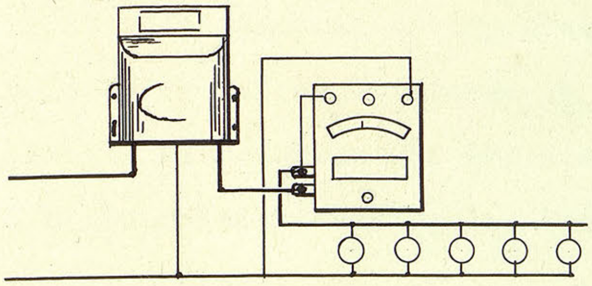
Since the angular force causing the armature to rotate is directly proportional to the magnetic field of the currents in the two coils and the retarding angular force also proportional to the speed, the armature must eventually rotate at such a velocity that the elecro-magnetic driving force is exactly equal to the retarding force. Then with a constant pressure maintained in the wattmeter coils for any length of time the number of revolutions of the armature, and therefore the travel of the dial hands will also be constant during the time, and proportional to the energy supplied.

Regulation is accomplished by moving these retarding magnets either toward or away from the disc's center, according as it is desirable to increase or decrease the speed. A very slight change either way makes considerable difference. To insure permanent success by this method of damping, it is essential that the magnets be aged so that they remain for an indefinite time unchanged in strength.

In the 100 ampere Thompson meter tested the following data were secured:--

| | |
|---|---|
| Pressure coil - - - - - | 308 ohms |
| Non-ind. Resistance - - - | 995 ohms |
| Armature - - - - - - - | 1227 ohms |
| Total shunt circuit - - - | 2530 ohms |
| Series coils -- Negligable | |

From the foregoing the losses in the different portions ~~that~~ at various voltages could easily be computed.



The diagram for testing by use of the Weston indicating wattmeter is shown in figure. For accuracy the employment of any other method is discouraged. Care should be taken to get the generator to the left, and the load to the right hand side of the meter, otherwise the disc will rotate backwards.

For computing the indicated watts the following formula is used:-

$$\text{Watts} = \frac{3600 \times K}{\text{sec. per rev.}}$$

; where K is the testing constant of the instrument, usually stamped upon the disc.

$$\text{And per cent error} = \frac{\text{true watts} - \text{indicated watts}}{\text{true watts}} \times 100$$

In order to secure the best results upon light loads the positive generator terminal should be connected with the post marked +. One of the great objections to these meters is the constant shunt loss, another that they tend to creep through the influence of the compensating coil. Their great advantage is that they may be employed upon either direct or alternating current circuits. A few curves showing the action of a meter of this type are shown elsewhere in this treatise.

The meter was first checked with a direct current, at normal voltage, then subjected to inductive and non-inductive loads at various voltages and frequencies, that its behavior under the different conditions might be observed.

With 110 volts, the upper limit, regulation is not as perfect as might be expected, the variation being as much as 5 % slow. It is presumed that an improvement might be made in the plotting of this curve for as it stands it is slightly misleading in some respects. Although on the whole a general tendency to run slow is exhibited notwithstanding the fact that it was checked correct at mean load (50 amp).

With 105 volts the regulation is vastly improved. Atabout half load (50 amp) the actual curve intersects the theoretical (red) but diverges from it to about 4 % slow at low load.

With 100 volts the real curve is practically parallel to the theoretical but is slow throughout and the same fault to about the same extent is present at 95 volts.

Of this set of direct current curves it is difficult to say at which voltage regulation is the best. If any one were selected however, it would be the one at 105 volts, the mean voltage for which the instrument was intended.

It must be understood that none of these curves go beyond half load for in testing it was impossible, with the service, to load above 50 or 60 amperes, where, it is presumed the meter would operate slightly fast, thus compensating for the lightlow load registration.

With the same setting as for direct currents, the meter was tested with alternating currents.

With 110 volts, 60 cycles, an exceptionally good curve was obtained, which, starting at low loads 4 % slow steadily approaches and finally intersects the theoretical curve at half load.

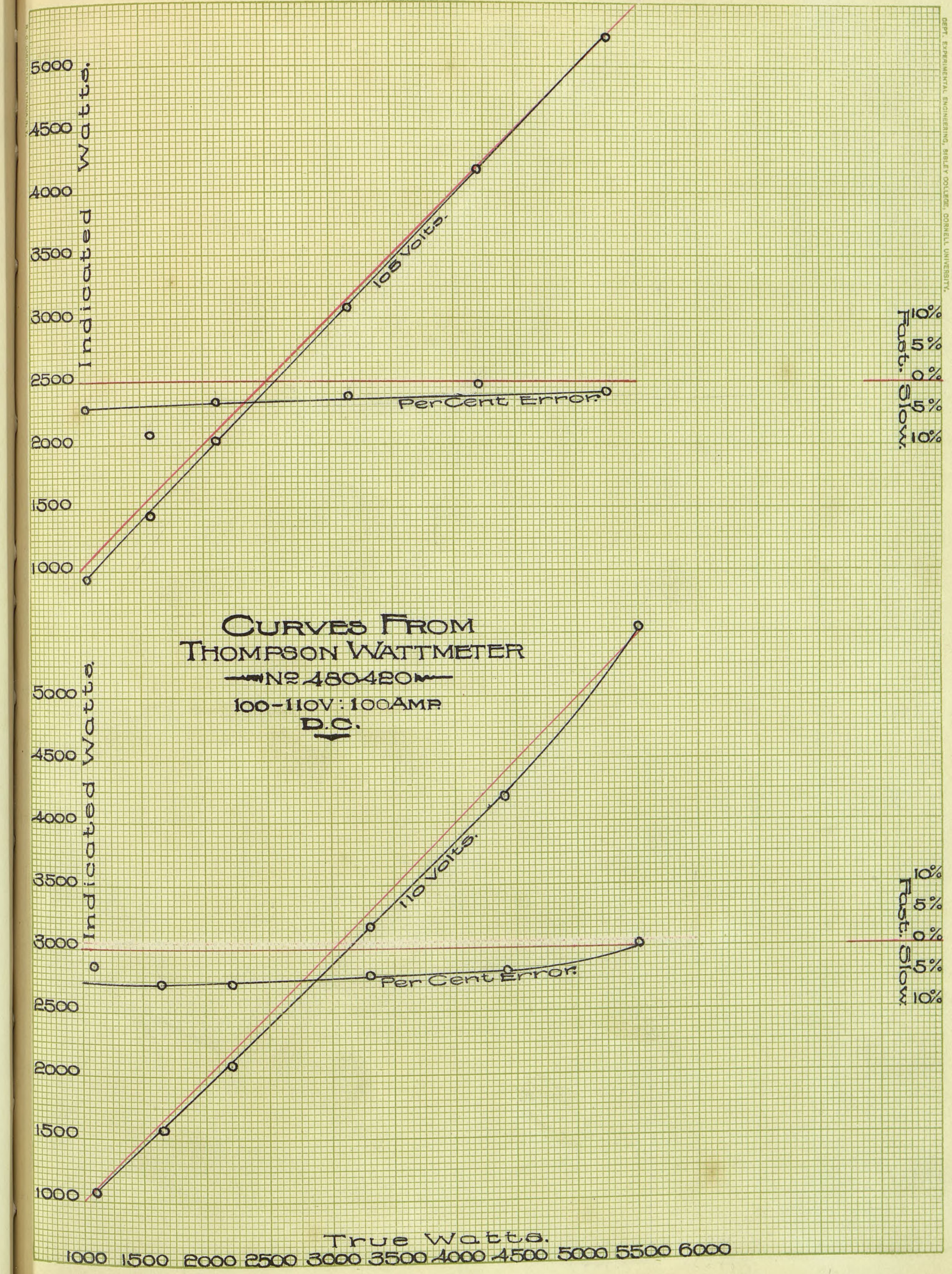
With 100 volts, 60 cycles, it appears to be more accurate at low loads and diverges from the theoretical as the load increases,

# DATA FROM CALIBRATION TESTS.

## THOMPSON RECORDING WATTMETER No 480420-100A.-100-110V.

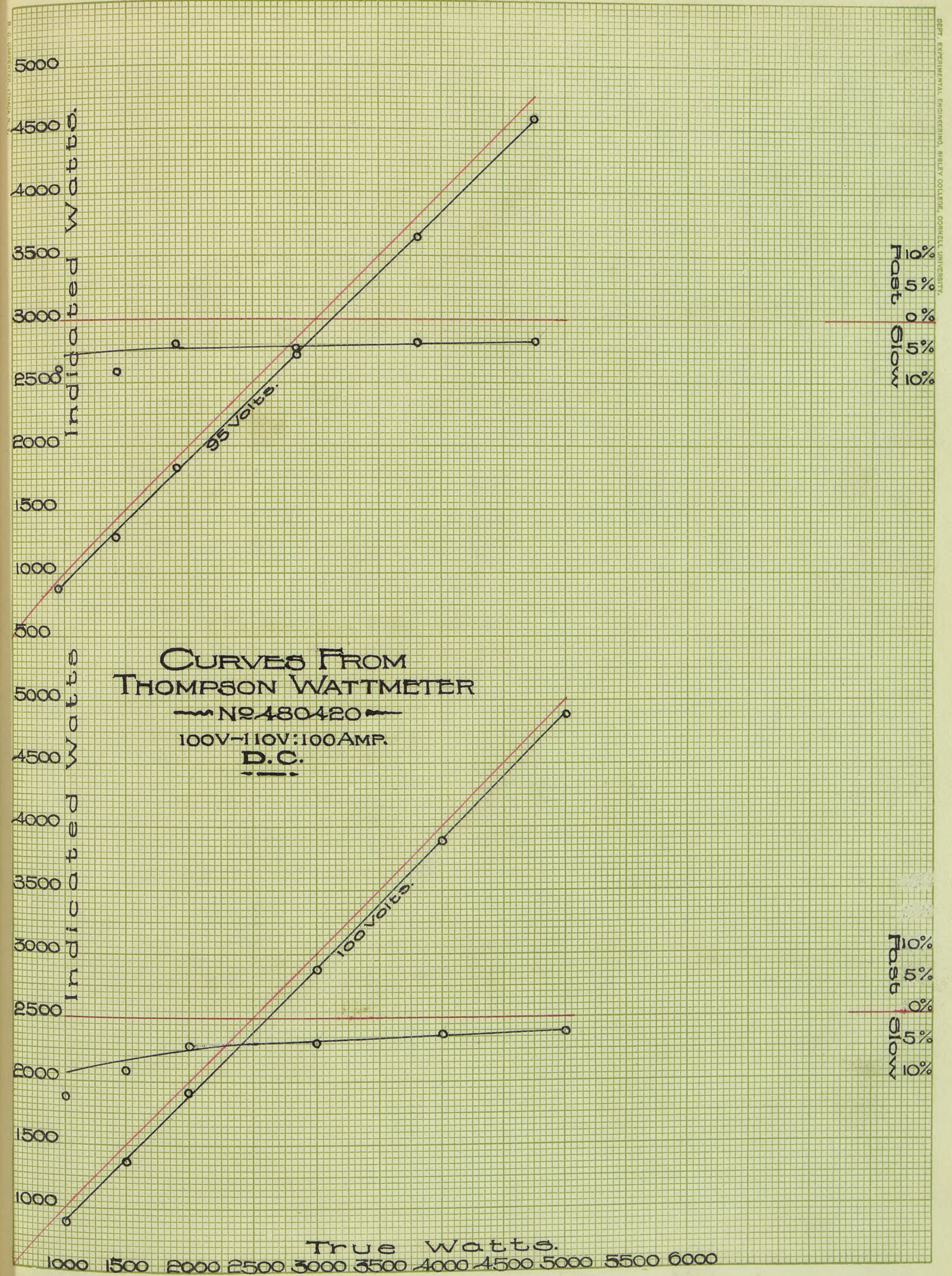
| Rev. of Disk | Time in Sec's. | Apparent Watts | True Watts | Error in Watts | % Fast | % Slow |
|---|---|---|---|---|---|---|
| 110 Volts (Continuous Current) | | | | | | |
| 10 | 26. | 5535 | 5500 | 35 | .64 | |
| 10 | 34 | 4240 | 4400 | 160 | | 3.64 |
| 10 | 45.5 | 3165 | 3300 | 135 | | 4.09 |
| 10 | 68. | 2080 | 2200 | 120 | | 5.46 |
| 10 | 92. | 1560 | 1650 | 90 | | 5.46 |
| 10 | 134.5 | 1070 | 1100 | 30 | | 2.73(?) |
| 105 Volts (Continuous Current) | | | | | | |
| 10 | 27.5 | 5240 | 5250 | 10. | | 1.9 |
| 10 | 34.5 | 4175 | 4200 | 25. | | .6 |
| 10 | 46.75 | 3080 | 3150 | 70. | | 2.22 |
| 10 | 7.1. | 2030 | 2100 | 70. | | 3.33 |
| 10 | 100. | 1440 | 1575 | 135. | | 8.66 |
| 10 | 146.6 | 984 | 1050 | 66. | | 4.4 |
| 100 Volts (Continuous Current) | | | | | | |
| 10 | 29.5 | 4885 | 5000 | 115 | | 2.3 |
| 10 | 37. | 3890 | 4000 | 110 | | 2.75 |
| 10 | 50. | 2880 | 3000 | 120 | | 4. |
| 10 | 75.5 | 1910 | 2000 | 90 | | 4.5 |
| 10 | 105 | 1370 | 1500 | 130 | | 8.66 |
| 10 | 165 | 874 | 1000 | 126 | | 12.6 |
| 95 Volts (Continuous Current) | | | | | | |
| 10 | 31.5 | 4575 | 4750 | 175 | | 3.68 |
| 10 | 39.5 | 3650 | 3800 | 150 | | 3.95 |
| 10 | 53. | 2720 | 2850 | 130 | | 4.56 |
| 10 | 79 | 1825 | 1900 | 75 | | 3.95 |
| 10 | 113. | 1275 | 1425 | 150 | | 8.28 |
| 10 | 164.5 | 875 | 950 | 75 | | 7.9 |
| 90 Volts (Continuous Current) | | | | | | |
| 10 | 33. | 4360 | 4500 | 140 | | 3.11 |
| 10 | 42 | 3430 | 3600 | 170 | | 4.73 |
| 10 | 56 | 2575 | 2700 | 125 | | 4.63 |
| 10 | 85.8 | 1680 | 1800 | 120 | | 6.67 |

| Rev. of Disk | Time in Sec's. | Apparent Watts | True Watts | Error in Watts | % Fast | % Slow |
|---|---|---|---|---|---|---|
| 110 Volts 60~ (A.C) | | | | | | |
| 10 | 26. | 5538 | 5500 | 38 | .69 | |
| 10 | 33 | 4364 | 4400 | 36 | | .82 |
| 10 | 43.8 | 3288 | 3300 | 12 | | .363 |
| 10 | 53.8 | 2140 | 2200 | 60 | | 2.68 |
| 10 | 90 | 1600 | 1650 | 50 | | 3.03 |
| 5 | 71.2 | 1011 | 1100 | 89 | | 8. |
| 105 Volts 60~ (A.C.) | | | | | | |
| 10 | 26.4 | 5465 | 5500 | 35 | | .64 |
| 10 | 33.8 | 4260 | 4400 | 140 | | 3.18 |
| 10 | 45. | 3200 | 3300 | 100 | | 3.16 |
| 10 | 67.6 | 2130 | 2200 | 70 | | 3.14 |
| 10 | 90.4 | 1595 | 1650 | 55 | | 3.33 |
| 10 | 139.2 | 1031 | 1100 | 69 | | 6.27 |
| 100 Volts 60~ (A.C.) | | | | | | |
| 20 | 53.5 | 5390 | 5500 | 110 | | 2. |
| 20 | 66.25 | 4490 | 4400 | 90 | 2.22(?) | |
| 10 | 45.5 | 3169 | 3300 | 131 | | 3.95 |
| 10 | 66.75 | 2160 | 2200 | 40 | | 1.82 |
| 10 | 91.5 | 1575 | 1650 | 75 | | 4.55 |
| 5 | 71.5 | 1060 | 1100 | 40 | | 3.64 |
| 110 Volts 50~ (A.C.) | | | | | | |
| 10 | 26.75 | 5380 | 5500 | 120 | | 2.12 |
| 10 | 33.5 | 4298 | 4400 | 102 | | 2.32 |
| 10 | 45.25 | 3182 | 3300 | 118 | | 3.58 |
| 10 | 68.5 | 2102 | 2200 | 98 | | 4.45 |
| 10 | 91. | 1582 | 1650 | 62 | | 4.12 |
| 10 | 143.5 | 1003 | 1100 | 97 | | 8.82 |
| 10 | 266.5 | 544 | 550 | 6 | | 1.09 |
| 110 Volts 60~ Inductive Load. | | | | | | |
| 10 | 25.75 | 5592 | 5500 | 92. | 1.67 | |
| 10 | 28.5 | 5052 | 4975 | 77. | 1.54 | |
| 10 | 31.75 | 4535 | 4500 | 35. | .77 | |
| 10 | 36 | 4000 | 4000 | 0. | .00 | .00 |
| 10 | 41.5 | 3469 | 3500 | 31. | | .89 |
| 10 | 48.2 | 2987 | 2950 | 37. | 1.25 | |
| 10 | 58.75 | 2451 | 2451 | 51 | 2.12 | |
| 5 | 38.4 | 1875 | 1875 | 0 | .00 | .00 |
| 5 | 55. | 1319 | 1030 | 289 | (?) | |
| 5 | 106.5 | 676 | 700 | 24 | | 3.42 |



CURVES FROM
THOMPSON WATTMETER
No 480420
100-110V: 100 AMP
D.C.

DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY.

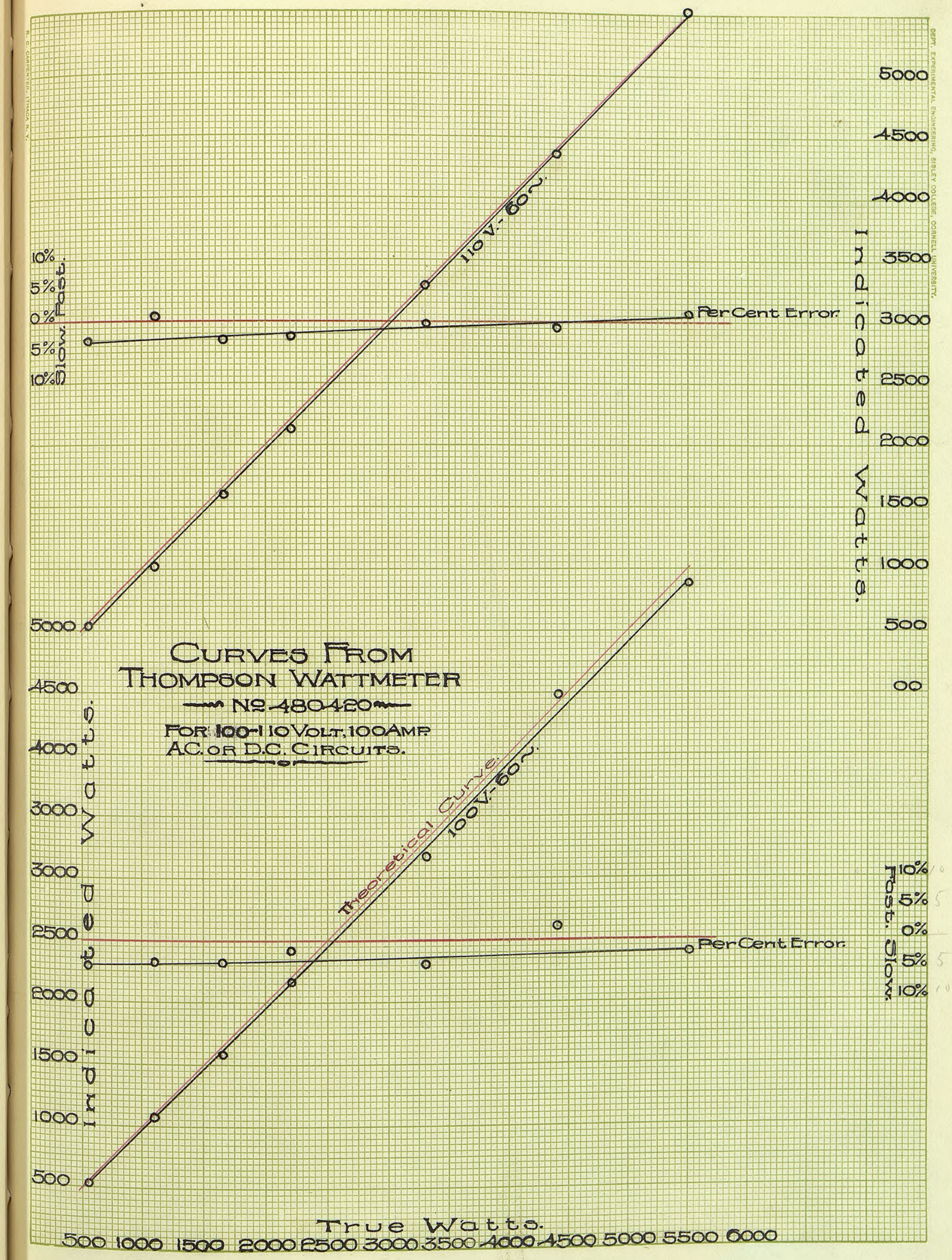


## CURVES FROM THOMPSON WATTMETER

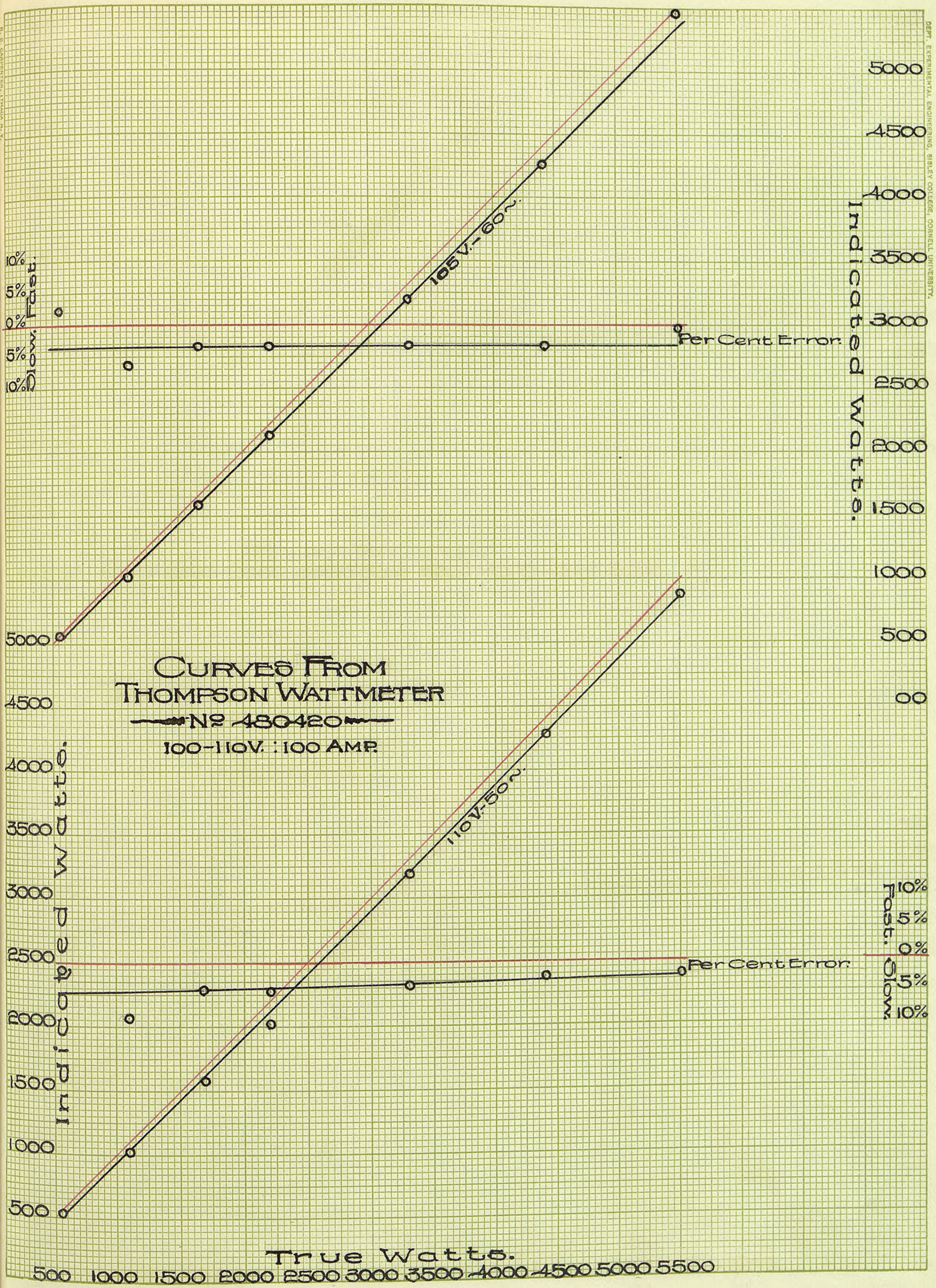
№ 480420

100V–110V : 100 AMP.

D.C.



CURVES FROM
THOMPSON WATTMETER
No. 480420
FOR 100-110 VOLT, 100 AMP.
A.C. OR D.C. CIRCUITS.

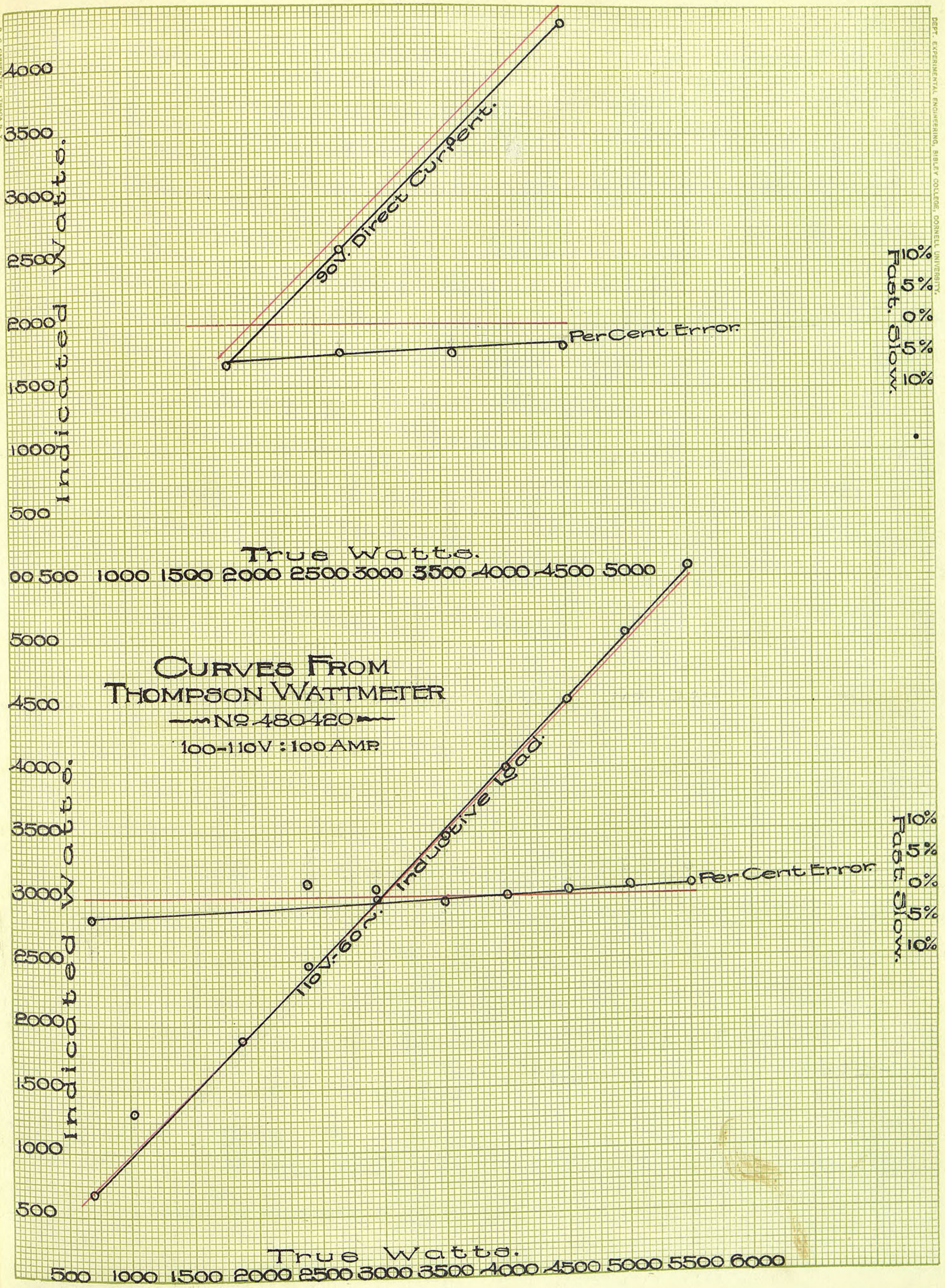


CURVES FROM
THOMPSON WATTMETER
Nº 480420
100-110V. : 100 AMP.

# CURVES FROM THOMPSON WATTMETER

No. 480420

100-110V : 100 AMP.



making an error of about 2% upon half load.

With 105 volts, 60 cycles the same remark holds only to a slightly greater extent showing about 3 % error half load. This seems to show that a drop in voltage causes a corresponding per cent error slow for the same load.

With 110 volts, 50 cycles we see that the error is 2 1/2 %, practically the same as with 105 volts, 60 cycles. The meter runs much slower than with 110 volts, 60 cycles. Hence lowering the cyclage has the same effect as lowering the voltage.

With the particular meter under test an inductive load (110 volts, 60 cycles) appears to produce the best regulation of all, a rather remarkable fact which cannot be satisfactorily explained with the data accumulated. This might not hold for loads above those experienced.

Notwithstanding the fact that, ordinarily, it is a very simple matter to read correctly the dials of wattmeters, yet commercial usage is oftimes responsible for serious displacements of the pointers thereon, in which case difficulty arises in the proper interpretation of the amount of power registered.

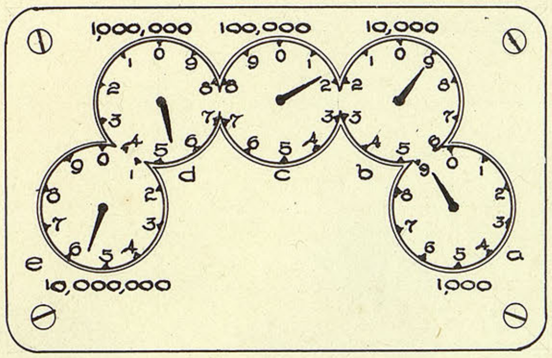
In view of this fact, a brief discussion, showing how to read correctly under such conditions will not be out of place.

Meters, as usually furnished, have five dials and are so geared that the first, third and fifth dials register clockwise, ~~wh~~ while the second and fourth register counterclockwise or vice versa as the case may be.

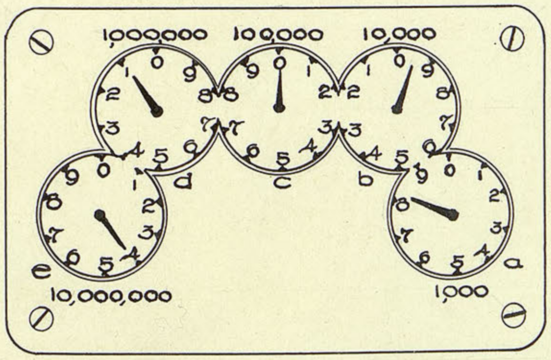
The first dial at the left registers 1 Kilowatt when the pointer has made one complete revolution, each division upon the dial representing 100 watts. Each succeeding dial registers ten times as much as the preceding one.

When reading a meter one should always read the lower figure of the two between which the pointer stands even though the pointer may be nearer the higher one. The reason for this will be apparent later.

In the illustrations given the different dials will be referred to as a - b - c - d and e, beginning at the right. The reading in the first meter shown is 5,518,900 and not 5,519,900 as might be supposed because the pointer of (b) should not indicate 9000 until the pointer at (a) has completed the revolution and is at zero or slightly beyond,



In the next figure the reading is 4,099,800 and not 4,109,800 as it might easily but erroneously be read. The reason for this is apparent on a little thought. The pointer of dial ( c) cannot rightly indicate zero until the pointer of (a) passes from 8 to 0; then the pointers of (b) and (c) will be at zero, the pointer (d) at 1, and the pointer (e) just past the zero mark.



These two examples will serve to place the observer upon the alert and will be sufficient to show him how to attack any paradox upon the meter dial with intelligence.

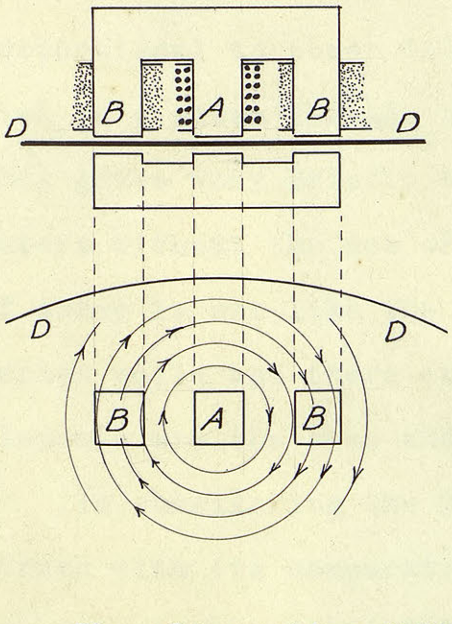
The indicated watt-hours must be multiplied by the constant, if any, of the instrument, in order to ascertain the number of watt-hours to be paid for; the difference, of course, between the last reading and the one preceding gives the watt-hours used during the time which has elapsed between the two readings.

## The Gutmann Recording Wattmeter.

The motor-meter of the commutator type was the great pioneer in both continuous current and alternating current systems but with the extended use of alternating current and progress in the manufacture of alternating current instruments, induction meters began to make their appearance. The honor of constructing the first alternating current induction meter is given by some to M. Blathy of Buda-Pesth, Hungary, who also pointed out the laws governing their action

The most important makes of induction wattmeters now on the American market are small, compact and of neat design. They have few complicated or delicate parts to get out of order, no commutator or commutator brushes and no moving or revolving coils.

As to the theory or underlying principles of the induction wattmeter, we feel that we cannot do better than quote from Franklin and Williamson. "The induction wattmeter is essentially a two-phase induction motor, of which the driving torque is porportional to the watts delivered to the receiving circuit. The armature disk is large and one edge of it moves between the poles of a permanent steel magnet (not shown in the cut) which causes the speed to be proportional to the driving torque as in the Thompson wattmeter.



The total current delivered to the receiving circuit passes through the coil of coarse wire on the lug A of the laminated iron core. The lugs BB are wound with fine wire which is connected across the mains.

The alternating current I in coil A produces a magnetic flux in lug A which is proportional to and in phase with I. This flux induces electromotive force in the disk DD, which is 90° ahead of the flux in phase, and this electromotive force produces current in the disk which is in phase with it. Therefore the eddy current in the disk is proportional to and 90° ahead of I. This eddy current flows along the circular lines shown in the figure, passing under the lugs BB.

The electromotive force E between the mains produces in coil BB a current which is proportional to and nearly 90° behind E. This current in its turn produces through B and B a flux which is 90° behind and proportional to E. The phase difference between this flux and the eddy current in the disk is equal to the phase difference $\theta$ between E and I.

The eddy current in passing under the lugs BB is pushed sideways by the flux from BB with a force the average value of which is proportional to the product of maximum eddy current X maximum flux X cosine of phase difference between the two, which according to the statements above, is proportional to $EI \cos \theta$, or to the power delivered to the receiving circuit. The speed of the disk is therefore proportional to power delivered and the total revolutions of the disk in a given time are proportional to the total work delivered." This gives very briefly the theory of the driving force of induction meters without the use of mathematical formulae. Indeed the meter of today is not like the cut in that there is no iron core in the series coils and there is but one pressure coil, but the essential e elements are the same and the same underlying principles apply.

In considering the Gutmann Wattmeter in particular we are first struck with its comparative lightness and neat appearance. The cover, secured by screws from the back, is of aluminum and fits the base or back so snugly as to render it dust, insect and moisture proof.

The revolving part of a Gutmann meter consists of an aluminum disk mounted upon a steel spindle about two inches long. The disk is slotted in spiral lines which causes the eddy currents to be disposed in the most favorable manner to produce torque, the portions of the disk between the slots acting as bars or conductors, as on a regular armature. The spindle is at its lower end polished to a ball-shaped point, while near its upper end is the worm which communicates motion to the recording train. The upper bearing is simply a brass post, but the lower bearing is a sapphire which, with a revolving element weighing only three-fourths of an ounce, occasions but little loss from friction.

The edge of the disk passes between the poles of a laminated steel magnet upon the back of which is wound the shunt coil. The two series coils are placed one above and one below the disk and close beside the laminated steel magnet. The coils are small and of few turns thus causing little or no inductive drop in the main circuit. The single permanent damping magnet is located at the opposite side of the meter and is of the ordinary type. The dial plate with five pointers is easily read through a small window. In front of the disk there is also a small window and this together with a black spot on the edge of the disk enables the revolutions of the disk to be counted for testing purposes without removing the cover.

The meter experimented upon in this case was one just received from the factory having been sold as a commercial meter to an electric light company. It was a meter of 5 amperes capacity, 100 volts, 60 cycles. The meter rack was fastened to a heavy stone wall and was absolutely free from vibration. The power was furnished by a 15 K. W. alternator, and the load was a bank of 110 volt, 16 candle power incandescent lamps. The alternator was connected as a single phase machine. The data were very carefully taken, one observer regulating the voltage and speed of the generator and the other timing the revolutions of the wattmeter disk by means of a stopwatch. The true watts were read on the new Weston Indicating Wattmeter (0-3 K.W.) inserted in the circuit so as not to measure the loss in the meter tested. For calculating the number of watts indicated by the meter the formula used is, Watts $= \frac{K R}{S} = \frac{3600 R}{T S}$ in which "R" is revolutions of disk, "S" is the time in seconds and "T" is the "train ratio" given on a slip with each meter. By train ratio is meant the number of revolutions per watt-hour made by the disk and in the case of a 5 ampere 100 volt Gutmann meter the train ratio is 4.

A test was made of the meter as it came from the factory, normal voltage and cyclage being maintained and the load varied from one lamp to 25% overload. The resulting curve shows that the meter is remarkably near correct, varying from about 2% to 0.1% slow. The meter was then calibrated exactly correct on one-half full load by swinging the damping magnet to or from the center of the disk as the meter ran slow or fast. Another series of readings were taken under normal conditions. The resulting curve shows the meter varying again from 2% to 0.3% slow. The calibration curve as drawn is open to criticism, for, by comparing the "per cent error" curves of the two tests mentioned, it will be seen that there is far more difference indicated in the "test curves" than either the "per cent error" curves or the data warrant. (It might be mentioned at this point that in comparing the curves of this meter with those of the Stanley meter or with those of the Thompson meter preceeding, it should be kept in mind that the scale to which the Gutmann curves are plotted is much larger than in the others, so that at first glance the discrepancies of the Gutmann meter would appear proportionally greater.) In comparing the curves taken at 105 volts, 60 cycles and 95 volts, 60 cycles, one high and one low voltage, it is a fact worth noticing that on the lower voltage the meter runs faster than on the voltage above normal. This fact is more noticable in the curves of the Stanley meter following. A glance at the curve taken at 100 volts, 50 cycles shows that here as in other meters the weak point is in its inability to operate correctly on different cyclages. This failure is of considerable importance as a varying cyclage is of common occurance in practice. With an inductive load the meter as adjusted for non-inductive load shows a considerable discrepancy, running from 4% to 6% slow. There is, however, in the Gutmann meter a device for compensating for inductive loads.

As a summary, considering the lightness and neatness of this meter, the fact that the working parts are so thoroughly protected from dirt, its accuracy as it comes from the factory and that it is fully protected by the company's guarantee, the station manager cannot make a very great mistake by installing Gutmann meters.

(See next page for data and curves.)

# GUTMANN RECORDING WATTMETER No 13937-100V.-5A. 60~

100V 60~ (As from factory)

| Rev. of Disk | Time in Sec's. | Apparent Watts | True Watts | Error in Watts | % Fast | % Slow |
|---|---|---|---|---|---|---|
| 5 | 91.8 | 49 | 50 | 1. | | 2. |
| 5 | 44.6 | 100.9 | 100 | .9 | .9 | |
| 10 | 57.4 | 156.8 | 160 | 3.2 | | 2. |
| 10 | 43.6 | 206.4 | 215 | 9.6 | | 4.47 |
| 10 | 34.6 | 260.1 | 265 | 4.9 | | 1.85 |
| 10 | 28.8 | 312.5 | 315 | 2.5 | | .8 |
| 10 | 24.4 | 368.8 | 375 | 6.2 | | 1.65 |
| 20 | 43. | 418.6 | 425 | 6.4 | | 1.5 |
| 20 | 38.4 | 468.7 | 475 | 6.3 | | 1.35 |
| 20 | 34.4 | 523.2 | 525 | 1.8 | | .34 |
| 20 | 31.2 | 576.3 | 575 | 1.3 | | .23 |
| 20 | 28.6 | 629.3 | 630 | .7 | | .11 |

100V. 60~ (Calibrated.)

| Rev. of Disk | Time in Sec's. | Apparent Watts | True Watts | Error in Watts | % Fast | % Slow |
|---|---|---|---|---|---|---|
| 3 | 49.2 | 54.8 | 50 | 4.8 | 9.6(?) | |
| 5 | 44.8 | 100.5 | 100 | .5 | .5 | |
| 10 | 59.6 | 151 | 150 | 1. | .67 | |
| 10 | 44.8 | 200.9 | 210 | 9.9 | | 4.72 |
| 10 | 36. | 250. | 250 | 0 | 0 | 0 |
| 10 | 30. | 300 | 310 | 10 | | 3.23 |
| 10 | 25.4 | 354.3 | 360 | 5.7 | | 1.84 |
| 10 | 22. | 409. | 415 | 6. | | 1.45 |
| 20 | 40. | 450 | 465 | 15. | | 3.23 |
| 20 | 36.2 | 500 | 515 | 15. | | 2.91 |
| 20 | 32.4 | 555.5 | 565 | 9.5 | | 1.68 |
| 20 | 29.4 | 612.2 | 615 | 2.8 | | .46 |
| 20 | 28. | 642.8 | 645 | 2.2 | | .34 |

105V. 60~

| Rev. of Disk | Time in Sec's. | Apparent Watts | True Watts | Error in Watts | % Fast | % Slow |
|---|---|---|---|---|---|---|
| 5 | 79. | 56.9 | 53 | 3.9 | 7.36 | |
| 5 | 40.4 | 111.2 | 110 | 1.2 | 1.9 | |
| 10 | 52.6 | 171.6 | 180 | 7.4 | | 4.1 |
| 10 | 40. | 225 | 232 | 7. | | 3.04 |
| 10 | 32. | 281.2 | 290 | 8.8 | | 3.04 |
| 20 | 53.2 | 338.3 | 345 | 6.7 | | 1.94 |
| 20 | 45.5 | 395.6 | 410 | 14.4 | | 3.5 |
| 20 | 40. | 450 | 465 | 15. | | 3.23 |
| 20 | 35.5 | 507 | 520 | 13. | | 2.5 |
| 20 | 32. | 562.4 | 585 | 22.6 | | 3.86 |
| 20 | 29. | 620.7 | 635 | 14.3 | | 2.26 |

95V. 60~

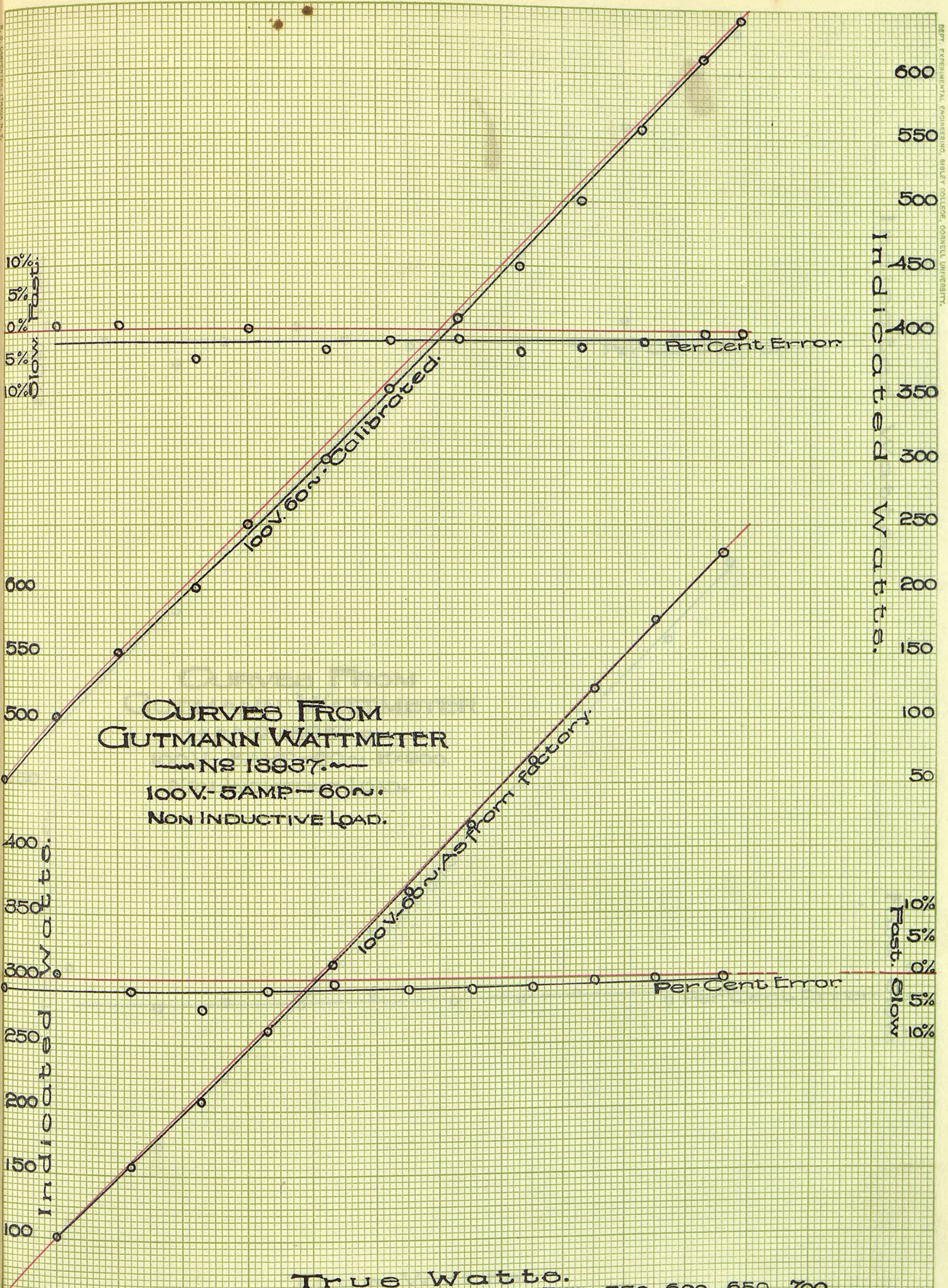
| Rev. of Disk | Time in Sec's. | Apparent Watts | True Watts | Error in Watts | % Fast | % Slow |
|---|---|---|---|---|---|---|
| 5 | 92.2 | 48.8 | 48 | .8 | 1.67 | |
| 5 | 48.4 | 92.8 | 92 | .8 | .87 | |
| 10 | 65.6 | 137.2 | 140 | 2.8 | | 2. |
| 10 | 49. | 183.7 | 195 | 11.3 | | 5.8 |
| 10 | 39.6 | 227.3 | 232 | 4.7 | | 2.01 |
| 10 | 32.6 | 276.1 | 275 | 1.1 | .4 | |
| 20 | 56.4 | 319.2 | 325 | 5.8 | | 1.79 |
| 20 | 49.2 | 365.9 | 375 | 9.1 | | 2.43 |
| 20 | 44.2 | 407.2 | 415 | 7.8 | | 1.88 |
| 20 | 39.8 | 455.7 | 465 | 9.3 | | 2. |
| 20 | 36. | 500. | 510 | 10. | | 1.96 |
| 20 | 32.2 | 559. | 550 | 9. | 1.67 | |
| 20 | 30.4 | 592.1 | 590 | 2.1 | .36 | |
| 20 | 28.2 | 636.2 | 640 | 3.8 | | .6 |

100V. 50~

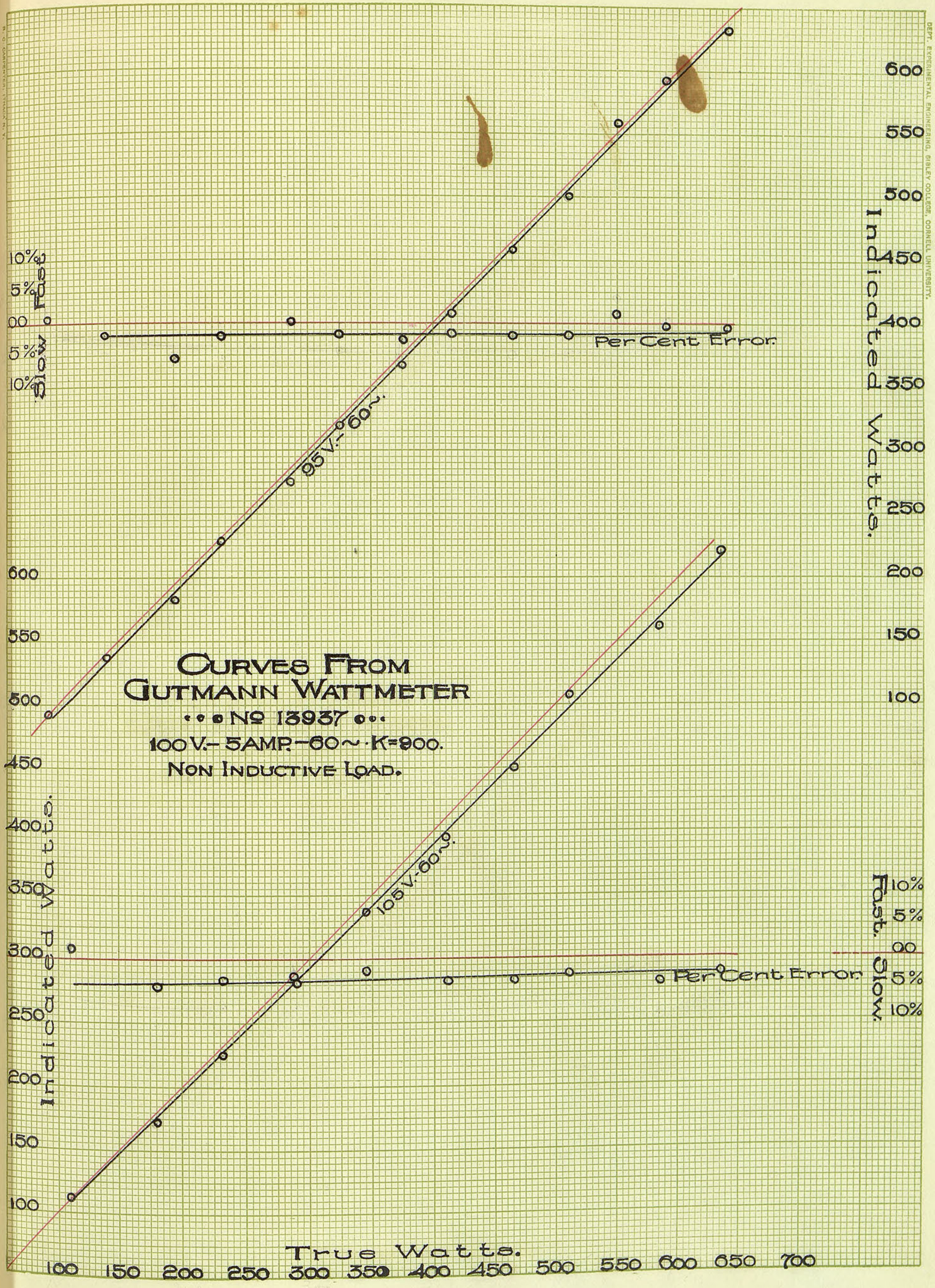
| Rev. of Disk | Time in Sec's. | Apparent Watts | True Watts | Error in Watts | % Fast | % Slow |
|---|---|---|---|---|---|---|
| 5 | 86.2 | 52.2 | 48 | 4.2 | 8.75 | |
| 5 | 45. | 100. | 100 | 0 | 0 | 0 |
| 5 | 31. | 145.1 | 155 | 9.9 | | 6.4 |
| 10 | 46.4 | 193.8 | 210 | 16.2 | | 7.72 |
| 10 | 37. | 243.2 | 255 | 11.8 | | 4.63 |
| 10 | 30.5 | 275.4 | 308 | 22.6 | | 7.35 |
| 20 | 52.5 | 342.8 | 355 | 12.2 | | 3.44 |
| 20 | 46.2 | 389.6 | 410 | 20.4 | | 4.98 |
| 20 | 41. | 439. | 452 | 13. | | 2.88 |
| 20 | 37.4 | 481.3 | 515 | 23.7 | | 4.6 |
| 20 | 34. | 529.3 | 565 | 35.7 | | 6.32 |
| 20 | 31.2 | 576.6 | 610 | 33.4 | | 3.46 |
| 20 | 29. | 620.7 | 660 | 39.3 | | 5.95 |
| 20 | 26.5 | 679.2 | 710 | 30.8 | | 4.34 |

100V. 60~ (Inductive Load)

| Rev. of Disk | Time in Sec's. | Apparent Watts | True Watts | Error in Watts | % Fast | % Slow |
|---|---|---|---|---|---|---|
| 10 | 76.6 | 117.5 | 120 | 2.5 | | 2.08 |
| 10 | 53.8 | 167.2 | 180 | 12.8 | | 7.12 |
| 10 | 42. | 214.3 | 230 | 15.7 | | 6.83 |
| 10 | 35. | 257.1 | 275 | 17.9 | | 6.5 |
| 10 | 29. | 310.3 | 325 | 14.7 | | 4.52 |
| 20 | 50.6 | 355.2 | 375 | 19.8 | | 5.3 |
| 20 | 44.4 | 405.4 | 425 | 19.6 | | 4.62 |
| 20 | 40. | 450. | 478 | 28. | | 5.86 |
| 20 | 36. | 500. | 528 | 28. | | 5.3 |
| 20 | 33. | 545.4 | 576 | 30.6 | | 5.32 |
| 20 | 30. | 600. | 630 | 30. | | 4.26 |



CURVES FROM
GUTMANN WATTMETER
No 18937.
100 V.- 5 AMP. — 60 ~.
NON INDUCTIVE LOAD.



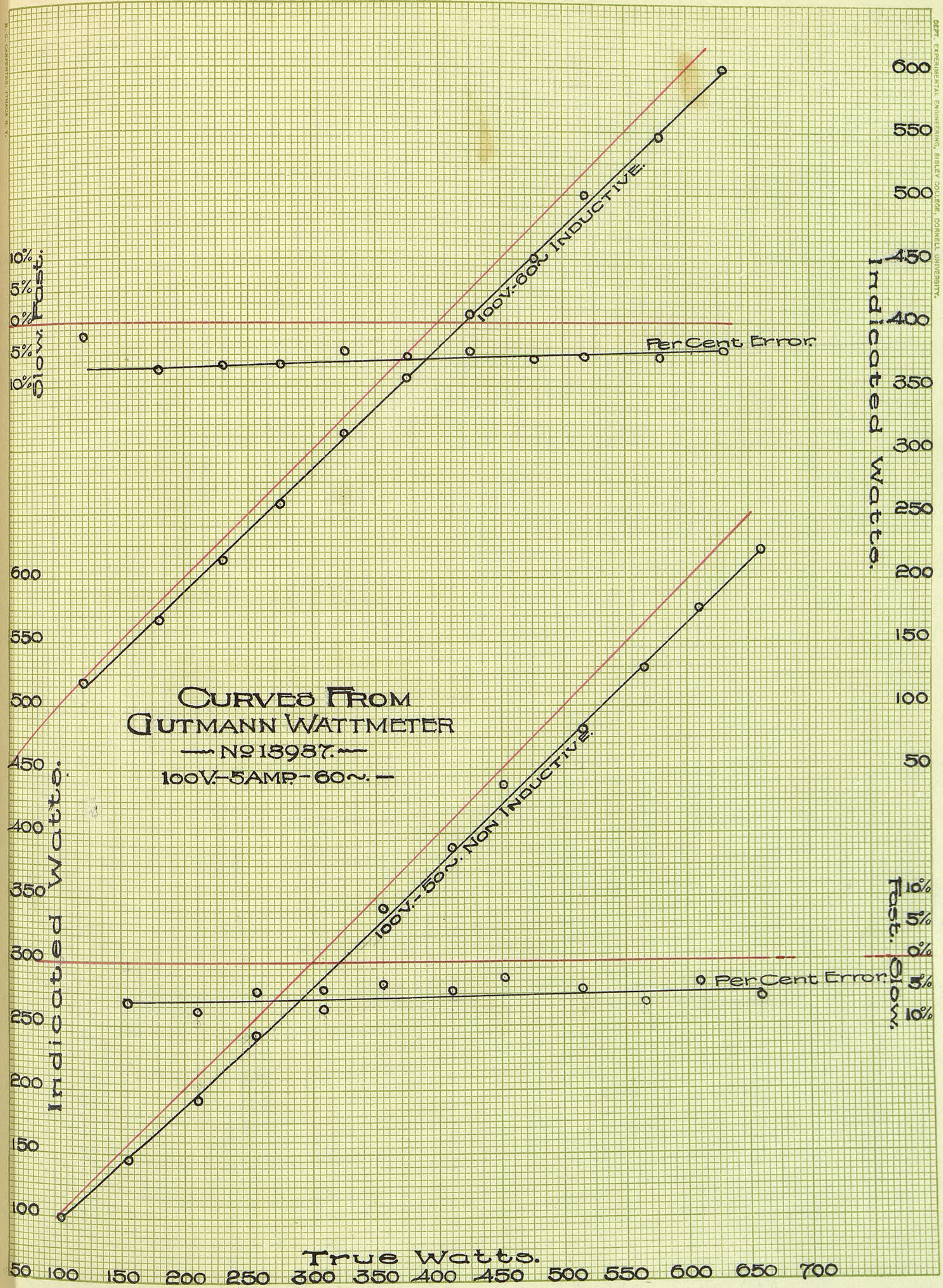
# CURVES FROM GUTMANN WATTMETER

•◦● No 13937 ●◦•

100 V.- 5 AMP. -60 ~ · K=900.

NON INDUCTIVE LOAD.

DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY.



CURVES FROM
GUTMANN WATTMETER
— Nº 13987. —
100V.-5AMP.-60~. —
100V.-60~ INDUCTIVE.
100V.-60~. NON INDUCTIVE.
Per Cent Error.
Per Cent Error.
Indicated Watts.
Indicated Watts.
True Watts.
Slow. Fast.
Fast. Slow.
10%
5%
0%
5%
10%
600
550
500
450
400
350
300
250
200
150
100
50
100
150
200
250
300
350
400
450
500
550
600
650
700
R. G. CARPENTER, ITHACA, N. Y.
DEPT. EXPERIMENTAL ENGINEERING, SIBLEY COLLEGE, CORNELL UNIVERSITY.

## The Stanley Recording Wattmeter.

A wattmeter that has attracted a good deal of attention on account of some decidedly new features, is the Stanley meter. The earliest patent date on a Stanley meter is March 11, 1890. It is an induction meter with a revolving disk of **aluminum mounted upon a soft** steel core or shaft. The claim of the Stanley Company is that that in their meters they have practically eliminated friction by a method of magnetic floation of the revolving element. In this method there are no supporting bearings and no jewels or end pivots to wear out. The soft steel core "C" (Fig.1) has a small hole drilled longitudinally from end to end through the center, and at both endsof the hole are located small phosphor bronze rings. The core and disk are placed in position as shown in Fig.1 and a piece of piano wire is drawn through the hole in the core and rings. By means of two stationary steel plugs or posts the wire is drawn tight thus becoming a straight stiff guide passing through the core. The wire fits the hole in the phosphor bronze rings loosely and thus the core is free to revolve around the guide. It must be noticed that the only points of contact between the wire and the core are on the bronze rings. The stationary plugs "A" and "B" are magnetized by the permanent magnet "M" and the lines of force pass through the soft steel core "C" and by means of the construction of the lower part of the core relieves the core and disk of any mechanical support. As the head "H" of the core falls below the line "ef," the lines of force, tending always to take the path of least reluctance, seek a path through the head, as the air-gap between "H" and any part of "B" is

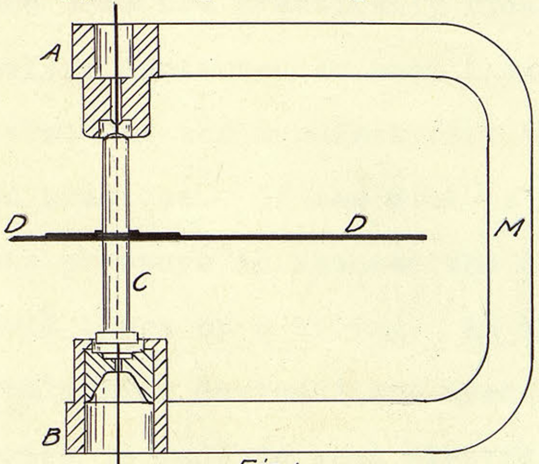


Fig.1

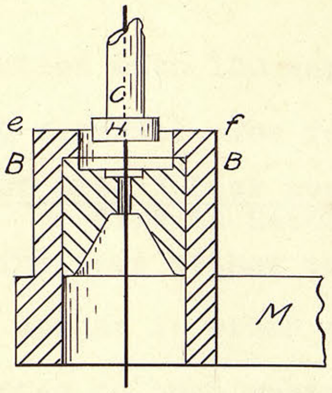


Fig.2

smaller than between the main part of the core "C" and any part of "B", but also as their course is upward through "C" they tend to pull "H" upward to a level with "ef." If it rises above "ef" on account of the magnetic pull exerted by "A" (Fig.1) on the upper end of the core, the lines of force tend to pull "H" down to a level with "ef" again. It will be seen, therefore, that the disk and core are practically floating on air with only the piano wire before mentioned to keep them in place. This method of support, termed by the manufacturers "Magnetic Flotation," is very successful in practice. If the disk is lifted or depressed by the finger, when the pressure is removed the disk will fly back to place as though held there by a spring. As there is practically no friction, no "balancing devices" are used to give it starting torque and as the meter is made in good electrical and mechanical balance there is no tendency to creep on account of the shunt current.

The series and potential coils are located in the back part of the meter and the damping device in the front part. The damping effect is accomplished by means of two permanent magnets with like poles on opposite sides of small adjustible iron or steel plugs between which the edge of the disk passes. The damping effect is regulated by moving these plugs nearer or farther from the disk by means of a couple of small adjusting screws. Like the Gutmann, it comes from the factory fully sealed and the guarantee expires with the breaking of the seal.

The meter experimented upon in this case was a 15 ampere, 110 volt, 60 cycle meter. The disk constant as stamped on the cover was "30 sec's.," which means that the time the disk required to make one revolution with 100 watts in the circuit at normal voltage and cyclage was 30 seconds. The formula for watts in the circuit is,

$$\text{Watts} = \frac{\text{Rev. of Disk X Disk constant X 100}}{\text{Time in Seconds}}.$$

The same method and apparatus was used as in testing the Gutmann meter and as in other tests it was desired that the meter should be subjected to such variations of voltage and cyclage as it would meet in actual practice. A test was made of the meter as it came from the factory and the data and curves show that it was remarkably accurate from low loads up to 25% overload. (As before mentioned in taking thee data the wide discrepancy in the first readings were attributed to inaccuracy in reading theindicating wattmeter on low loads.) It will be noticed that the meter as it came from the factory was about 1% fast increasing slightly on overload. It is customary, however, to favor the consumer if possible, hence the meter should run a small per cent slow if not strictly accurate.

By adjusting the plugs on the damping device, bringing them closer to the disk, the movement of the disk was retarded. The meter was regulated to read exactly correct on about two-thirds full load and datd for a calibration curve taken under normal conditions. The curve as shown is a little at fault in that it should rise a little on full load and overload according to the data and in order to agree with the "per cent error curve." It shows, however, that the meter is very nearly accurate throughout its range. At 115 volts and normal cyclage the meter runs just a little slow but less than 1% while at 100 volts and normal cyclage the current and datd show it to run about 1% fast. At normal voltage and 50 cycles it does not follow the indicating wattmeter so well, runningmabout 3% slow. This particular part of the test is, moreover, an important one for the speed of a generator is apt to vary and in an alternator the cyclage is governed by the speed, hence as the cyclage is quite often unsteady in practice, a meter whose accuracy is affected by these changes certainly has a weak point. Yet it must be kept in mind that this one test can scarcely be taken as conclusive on this point. Under inductive load at normal voltage and cyclage the resulting curves almost exactly coincide with the theoretic curves showing that the Stanley meter works equally well on inductive and on non-inductive loads without adjusting for the different kinds of loads. This excellent quality is possessed perhaps by no other meter on the market.

On the whole the results of the test are very satisfactory and they indicate a very efficient and accurate meter and one on which the station manager can rely.

(See next page for data and curves.)

## STANLEY RECORDING WATTMETER No 41630-110V-15A-60~

110V. 60~ (As from factory)

| Rev. of Disk | Time in Sec's. | Apparent Watts | True Watts | Error in Watts | % Fast | % Slow |
|---|---|---|---|---|---|---|
| 5 | 104.4 | 143.7 | 125 | 18.7 | 15.(?) | |
| 5 | 59.4 | 252.5 | 250 | 2.5 | 1. | |
| 10 | 78.8 | 380.7 | 375 | 5.2 | 1.5 | |
| 10 | 59.4 | 505. | 500 | 5. | 1. | |
| 10 | 47.8 | 627.6 | 625 | 2.6 | .4 | |
| 10 | 34.6 | 867. | 850 | 17. | 2. | |
| 20 | 53.4 | 1123.6 | 1100 | 23.6 | 2.1 | |
| 20 | 44.2 | 1357.4 | 1350 | 7.4 | .6 | |
| 20 | 37.6 | 1595.7 | 1575 | 20.7 | 1.3 | |
| 20 | 35. | 1714.2 | 1700 | 14.2 | .8 | |
| 20 | 29.6 | 2027 | 1975 | 52. | 2.6 | |
| | | | | | | |

110V. 60~ (Calibrated)

| Rev. of Disk | Time in Sec's. | Apparent Watts | True Watts | Error in Watts | % Fast | % Slow |
|---|---|---|---|---|---|---|
| 2 | 87. | 68.9 | 60 | 8.9 | 14.8(?) | |
| 5 | 76. | 197.4 | 200 | 2.6 | | 1.3 |
| 10 | 85.8 | 349.6 | .385 | 35.4 | | 9.2 |
| 10 | 52.8 | 568.2 | 570 | 1.8 | | .3 |
| 10 | 39.6 | 757.5 | 760 | 2.5 | | .3 |
| 10 | 32. | 937.5 | 940 | 2.5 | | .3 |
| 20 | 53. | 1132. | 1120 | 2. | 1.9 | |
| 20 | 46.6 | 1287.5 | 1285 | 2.5 | .2 | |
| 20 | 40.6 | 1477.8 | 1475 | 2.8 | .2 | |
| 20 | 36. | 1666.6 | 1650 | 16.6 | 1. | |
| 20 | 32.4 | 1851.8 | 1830 | 21.8 | 1.2 | |
| 20 | 29.5 | 2033.9 | 2040 | 6.1 | | .3(?) |

115V. 60~

| Rev. of Disk | Time in Sec's. | Apparent Watts | True Watts | Error in Watts | % Fast | % Slow |
|---|---|---|---|---|---|---|
| 4 | 157.2 | 76.3 | 65 | 11.3 | 17.4(?) | |
| 5 | 71.6 | 209.5 | 215. | 5.5 | | 2.56 |
| 10 | 72.2 | 417.5 | 420 | 2.5 | | .6 |
| 10 | 48.4 | 619.8 | 625 | 5.2 | | .83 |
| 10 | 33.6 | 892.8 | 900 | 7.2 | | .8 |
| 10 | 25.6 | 1171.8 | 1160 | 11.8 | 1.02 | |
| 20 | 42.2 | 1421.8 | 1430 | 8.2 | | .57 |
| 20 | 35.6 | 1685.4 | 1675 | 10.4 | .62 | |
| 20 | 32.4 | 1851.8 | 1880 | 28.2 | | 1.5 |
| 20 | 29.2 | 2054.8 | 2065 | 10.2 | | .5 |
| | | | | | | |

100V. 60~

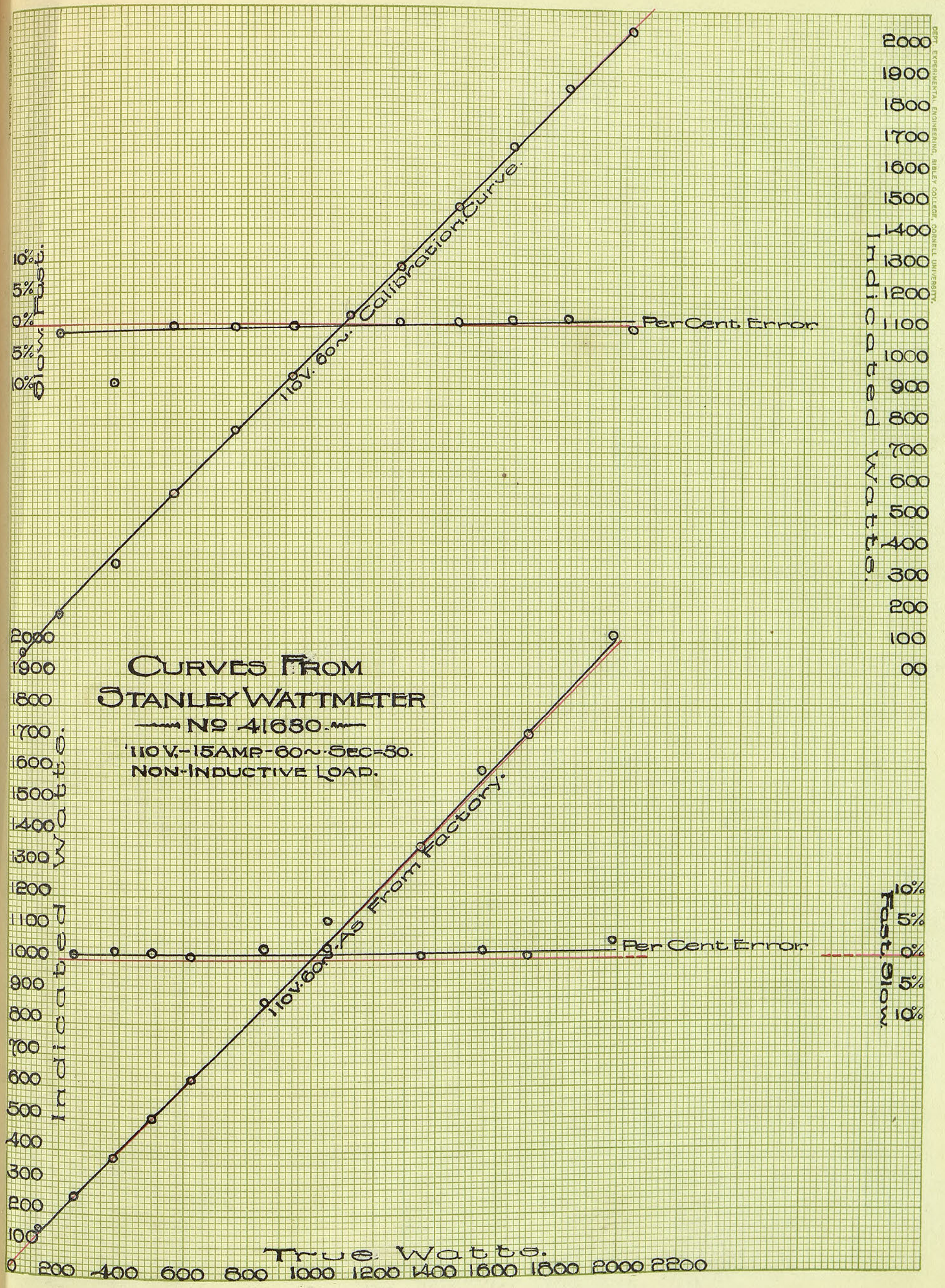
| Rev. of Disk | Time in Sec's. | Apparent Watts | True Watts | Error in Watts | % Fast | % Slow |
|---|---|---|---|---|---|---|
| 2 | 103.2 | 58.1 | 50 | 8.1 | 16.2(?) | |
| 4 | 75.6 | 158.7 | 150 | 8.7 | 5.8 | |
| 5 | 47.4 | 316.4 | 310 | 6.4 | 2.06 | |
| 5 | 28.8 | 520.8 | 520 | .8 | .15 | |
| 10 | 41. | 731.7 | 720 | 11.7 | 1.66 | |
| 10 | 32.4 | 925.9 | 915 | 10.9 | 1.19 | |
| 20 | 53.6 | 1119.4 | 1115 | 4.4 | .38 | |
| 20 | 45. | 1333.3 | 1315 | 18.3 | 1.4 | |
| 20 | 38.8 | 1546.3 | 1520 | 26.3 | 1.74 | |
| 20 | 34.6 | 1734.1 | 1720 | 14.1 | .82 | |
| 20 | 31. | 1935.5 | 1900 | 35.5 | 1.87 | |
| 20 | 29.8 | 2013.4 | 2000 | 13.4 | .67 | |

110V. 50~

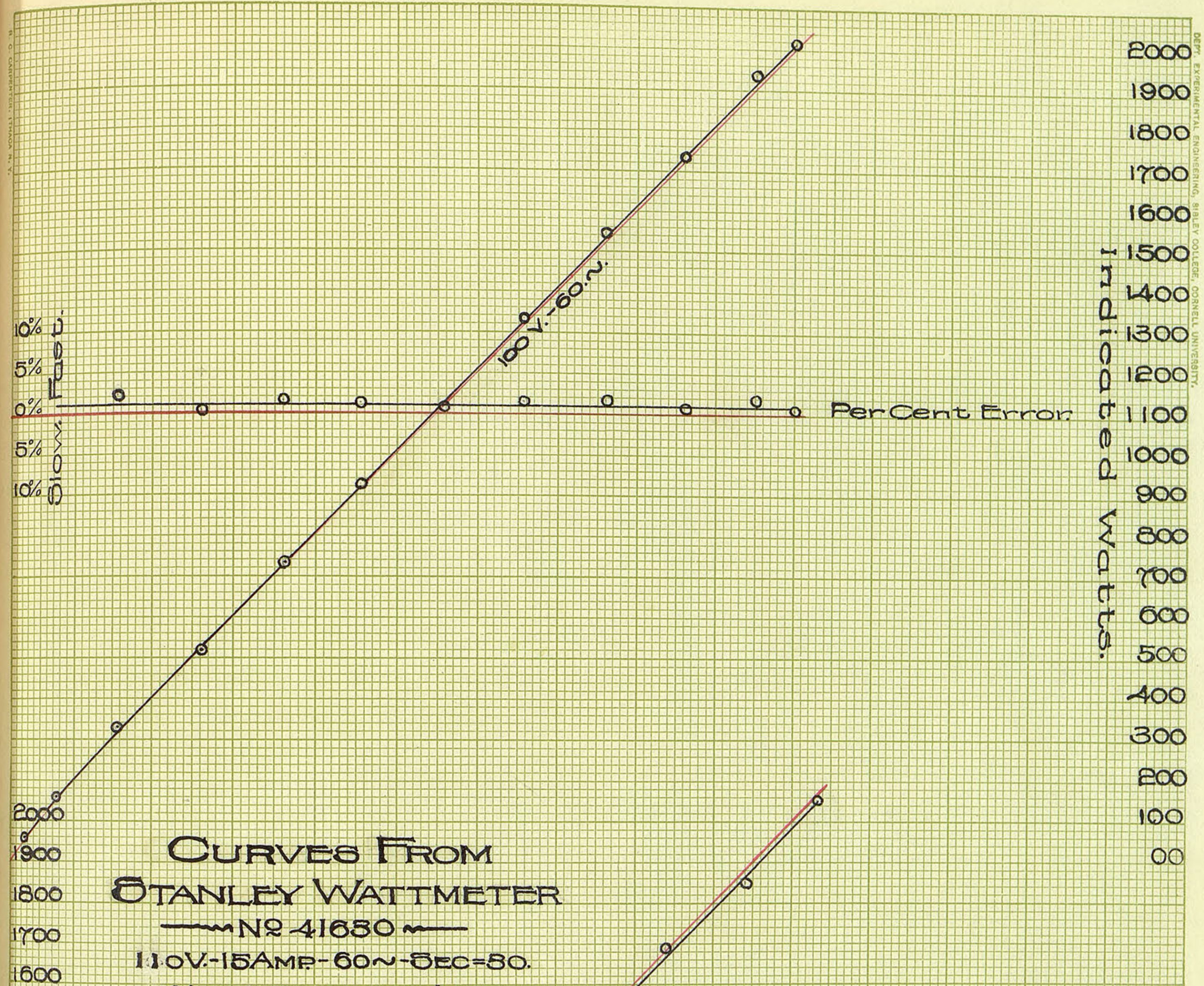
| Rev. of Disk | Time in Sec's. | Apparent Watts | True Watts | Error in Watts | % Fast | % Slow |
|---|---|---|---|---|---|---|
| 2 | 90 | 66.6 | 60 | 6.6 | 11.(?) | |
| 3 | 47 | 191.5 | 195 | 3.5 | | 1.79 |
| 5 | 47.6 | 315.1 | 320 | 4.9 | | 1.56 |
| 10 | 53. | 566. | 590 | 24. | | 4.6 |
| 10 | 37.6 | 797.8 | 820 | 22.2 | | 2.71 |
| 10 | 29. | 1034.5 | 1060 | 25.5 | | 2.41 |
| 10 | 23.6 | 1271.1 | 1315 | 33.9 | | 2.58 |
| 20 | 39.8 | 1507.5 | 1550 | 42.5 | | 2.74 |
| 20 | 34.2 | 1754.3 | 1800 | 45.7 | | 2.54 |
| 20 | 30. | 2000 | 2030 | 30. | | 1.48 |
| | | | | | | |
| | | | | | | |

110V. 60~ (Inductive Load.)

| Rev. of Disk | Time in Sec's. | Apparent Watts | True Watts | Error in Watts | % Fast | % Slow |
|---|---|---|---|---|---|---|
| 5 | 101.2 | 148.2 | 150 | 1.8 | | 1.2 |
| 5 | 54.8 | 273.7 | 280 | 6.3 | | 2.25 |
| 5 | 32.2 | 465.8 | 460 | 5.8 | 1.26 | |
| 10 | 46. | 652.1 | 650 | 2.1 | .32 | |
| 10 | 35.8 | 837.9 | 840 | 2.1 | | .25 |
| 10 | 28. | 1071.4 | 1080 | 8.6 | | .8 |
| 20 | 45.5 | 1318.7 | 1320 | 1.3 | | .1 |
| 20 | 38.8 | 1546.3 | 1550 | 3.7 | | .24 |
| 20 | 33.6 | 1785.7 | 1790 | 4.3 | | .24 |
| 20 | 29.8 | 2013.4 | 1990 | 23.4 | 1.18 | |
| 20 | 27.4 | 2189.8 | 2170 | 19.8 | .92 | |



CURVES FROM
STANLEY WATTMETER
Nº 41680.
110 V.-15 AMP.-60~-SEC=30.
NON-INDUCTIVE LOAD.



## CURVES FROM STANLEY WATTMETER

No 41630

110V.-15AMP.-60~-SEC=30.

NON-INDUCTIVE LOAD.

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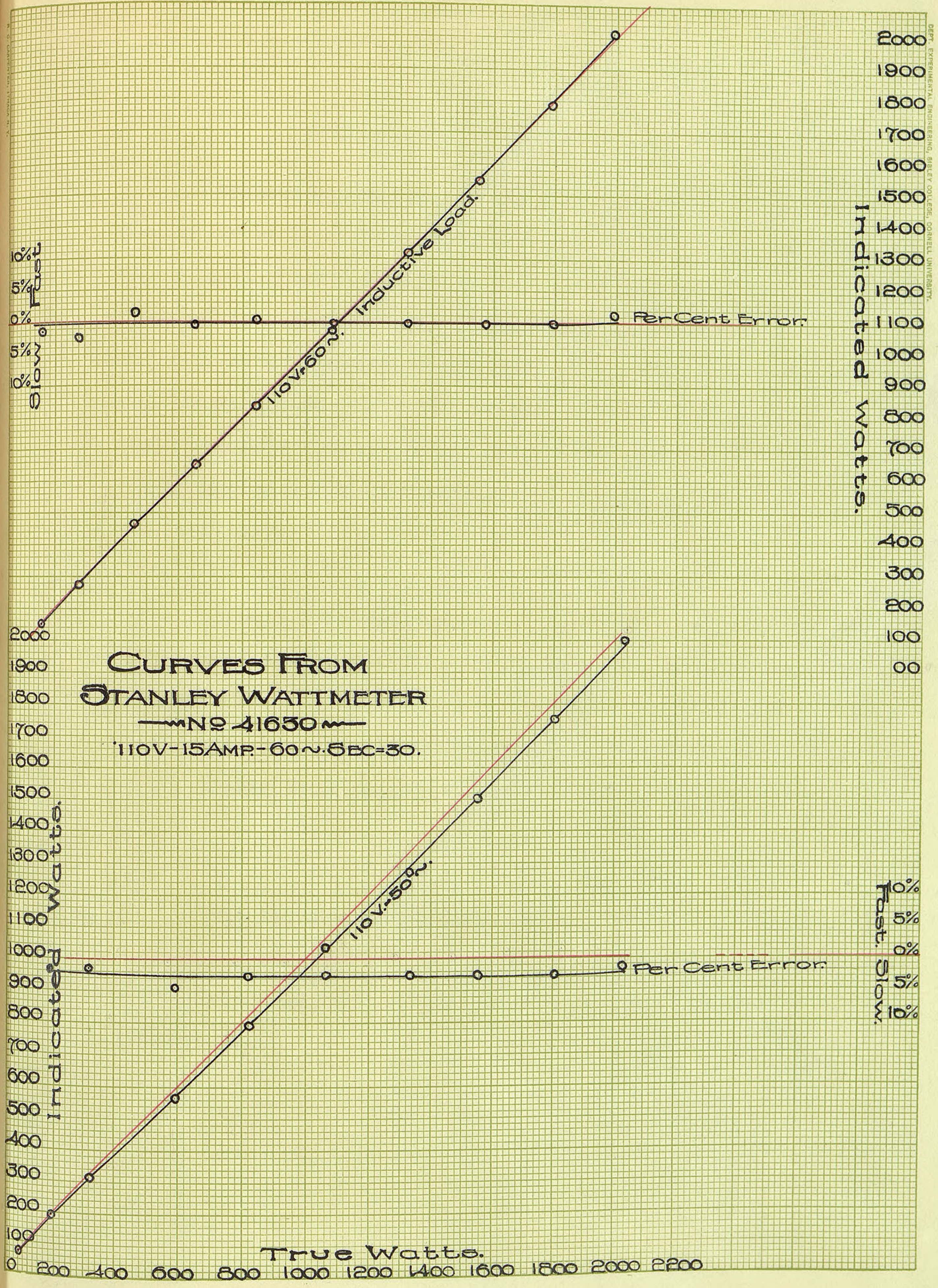

CURVES FROM STANLEY WATTMETER

—No 41650—

110V-15AMP.-60~.SEC=30.

## CONCLUSIONS AND PRACTICAL SUGGESTIONS.

Wattmeters should, if possible, be installed on a solid support or at least not be subjected to sudden shocks or jars. Meters with a heavy moving element, as the Thompson meter, are more affected by vibration than an induction meter for instance, because there is more pressure on the jewel bearing and also because a meter compensated for a considerable amount of friction will be almost sure to "creep" if subjected to a continuous vibration. Meters should not be subjected to excessive heat or cold or fumes from chemicals.

From a few tests made by the authors but not otherwise recorded here, the effect of a considerable mass of unmagnetized iron was found, even with the cover of the meter removed, to be very small, practically negligible, and with the cover of the meter on and acting as a shield, it would be unappreciable.

The indicating wattmeter method is the most accurate method of checking and calibrating as there is less chance for error in reading instruments. Standard lamps are sometimes used for commercial tests.

In timing meters with a stop watch the more revolutions the disc makes in the time taken, the less chance for error.

A split stop-watch is preferable for in this type a more instantaneous start of the hand can be obtained and besides many watches are not equally accurate at all points of the circumference.

In the case of the New York Edison Company, care is taken that the meters do not run more than 2 % fast or 5 % slow. Meters are checked at regular intervals and at the customer's request.

If occasion demands that the magnets be removed, in replacing care should be taken to place the North pole on top of the disc.

Use little or no oil in the clock work or on the jewel bearing; if any, it should be porpoise oil or jeweler's oil.

The jewel bearing will deteriorate faster with an alternating current than with a direct current.

"For lighting only, fuses should be placed on the service side and the switch shpuld be on the load side of the meter. For motor purposes, the meter should be fused on both sides and the switch should be on the load side. This arrangement will prevent any "kick" from the motor fields passing through and breaking down the potential path of the meter."

Before a test is made the meter should be allowed to warm up for with the increased resistance in the potential coil the meter will slow down.

In the commutator type of meter the commutator and brushes should be cleaned occasionally. Remove the brushes and use a fine cut file or if not badly worn polish with a piece of tape stretched on a piece of wood. A simple way of cleaning both brushes and commutator is to slip a piece of narrow, cotton tape around the commutator and under the brushes and draw it backward and forward over the surface of the commutator. If surfaces are very rough, $ use crocus cloth in the same manner and polish with a piece of tape. To prepare the crocus cloth lay the strip upon a flat surface and draw a moist cloth over it to remove the greater portion of the crocus and when dry rub briskly over the surface of a nail to soften it and wear it down. Be careful not to bend or twist the brushes out of shape by catching them with the frayed ends of the cloth. It is better to remove the brushes.

In modern meters the speed can be increased or retarded about 16 % by moving the magnets. In repairing a meter if it is not possible to properly calibrate it by moving the magnets, a rough correction can be made with the motor type of meter by changing the resistance in series with the armature.

Magnets will become"aged" if kept near stray currents. Meters should not be installed near running belts or machines or heavy leads, etc. A short circuit will sometimes "knock down" a a permanent magnet, thus allowing a meter to speed up.