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*** START OF THE PROJECT GUTENBERG EBOOK THE FIFTEEN WATT TUNGSTEN LAMP ***

THE FIFTEEN WATT TUNGSTEN LAMP

BY

CLAIR ELMORE ANDERSON

B. S., University of Illinois, 1911

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

MASTER OF SCIENCE

IN ELECTRICAL ENGINEERING

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

1912

UNIVERSITY OF ILLINOIS
THE GRADUATE SCHOOL

May 31, 1912

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

CLAIR ELMORE ANDERSON

ENTITLED THE FIFTEEN WATT TUNGSTEN LAMP

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

Emstberg
In Charge of Major Work

Emstberg
Head of Department

Recommendation concurred in:

Morgan Brooks
Alley Blaine
J.M. Bryant

Committee
on
Final Examination

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THE 15 WATT TUNGSTEN LAMP

I. INTRODUCTION.

Since the introduction of the tungsten lamp some five years ago, the manufacturers have attempted continually to produce smaller and smaller units in the standard voltages. The latest lamp offered today is the 115 volt, 15 watt, tungsten, and it is the purpose of this paper to show the characteristics of this lamp, how it compares with the larger units as to life under different conditions and its behavior in general.

First of all, it must be borne in mind that these tests have been made upon a comparatively small number of lamps, and for that reason the results should not be taken as absolutely conclusive. For the life tests, at least 100 lamps should have been used under each condition, but this was impossible because of the expense.

Special attention has been given to the phenomenon of "overshooting". An entire year could have easily been spent investigating this subject, and the writer regrets that lack of time has prevented more elaborate and comprehensive tests of this strange phenomenon.

II. DESCRIPTION OF LAMPS AND TESTS.

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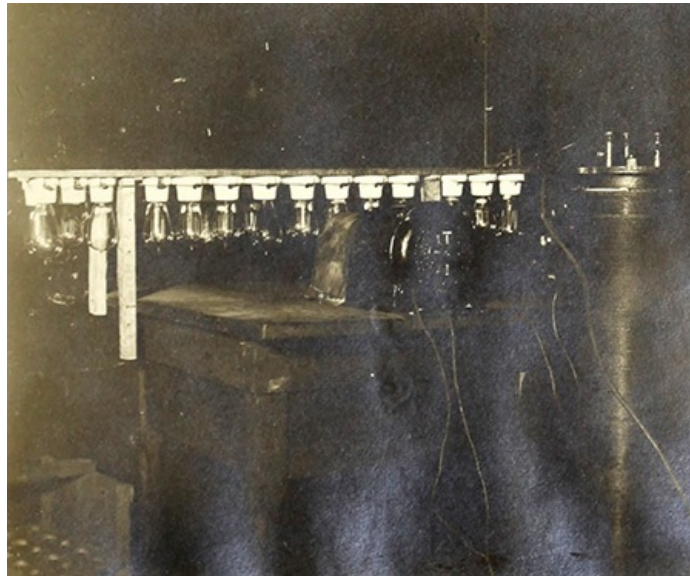
The total number of 15 watt lamps tested was 24, one half of which was obtained directly from the manufacturer and the other half bought in open market. It is well to mention at this time that this may have been the cause of the different qualities as brought out by the life tests.

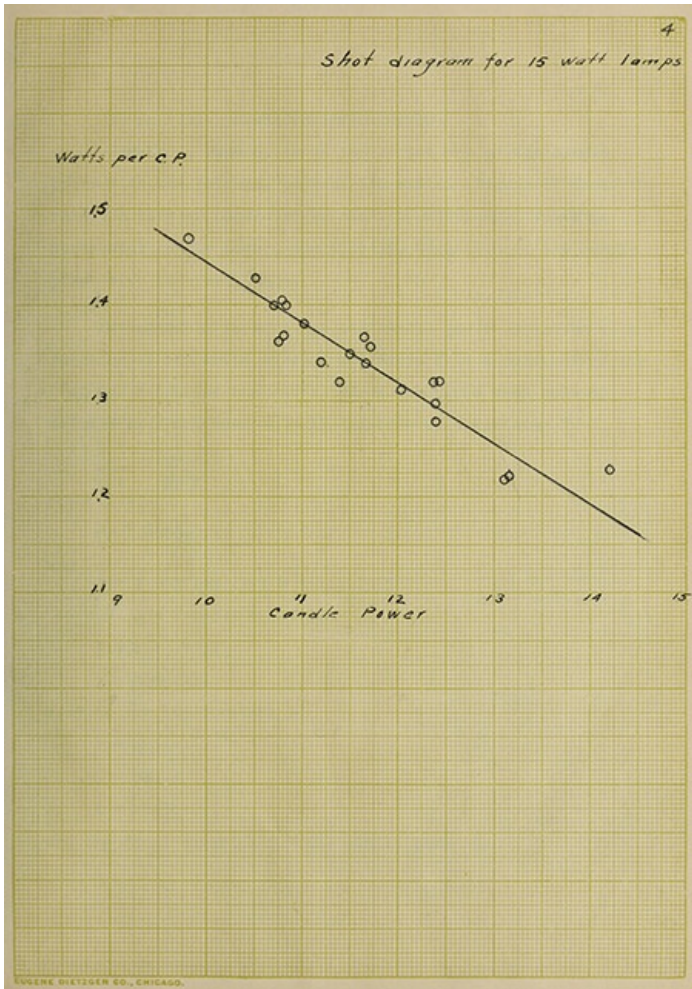
The lamps were rated at 1.31 watts per horizontal candle power and were supposed to have a useful life of 1000 hours. The voltage ratings of those obtained from the factory were 114 - 112 - 110 and those bought in open market were 115 - 113 - 111. The correct efficiency of the lamps as found by test was 1.34 watts per candle power. A shot diagram follows which shows the actual rating of the lamps at high efficiency.

All readings were made by a Lummer-Brodhun photometer and the voltmeters and ammeters used were carefully standardized. The ammeter was placed beyond the voltmeter in order to get the true current taken by the lamp. The drop across the ammeter was taken into account in the voltmeter readings.

Life tests were made under two conditions, namely, a shock test where the lamps received severe vibrations and a test under ideal conditions, i.e. no jar and constant voltage. In order to obtain vibrations for the lamps upon the shock test, a small motor, with its shaft pulley off set, was screwed rigidly to a table. The lamps were placed in a normal position upon the table by means of wooden frames. The result was that when the motor was running it had a pounding effect, thus putting the table, consequently the lamps, in a state of severe vibration. The filaments of the lamps could be seen violently shaking for some distance. The test was indeed a hard one, and one that would not be found in many actual cases. It is very doubtful if railway lamps are subjected to such a strain and they are of the heavy filament low voltage type. The following photograph shows the arrangement above described. Ten 15 watt lamps were used on this test, the remainder shown being 20 and 25 watt and carbons.

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Shot diagram for 15 watt lamps

III. CHARACTERISTIC CURVES.

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Figure 1, Page 8, shows the variations of the candle power with the voltage, current and watts. Figure II shows the relation between candle power and the efficiency, watts per horizontal candle power, and also the variation of the candle power with the resistance.

An empirical formula for the candle power expressed as a function of the watts is $cp = KW^x$ where K is a constant of the lamp and W denotes the watts. From the curve when $cp = 5$, watts = 11.1 and when $cp = 15$, watts = 17.5 dividing

$$cp_1/cp_a = KW_1^x/KW_a^x$$

substituting

$$5/15 = 11.1^x/17.5^x$$

and

$$\begin{aligned} \log 3 + x \log 11.1 &= x \log 17.5 \\ .4771 + 1.0453x &= 1.2430x \\ .198x &= .4771 \\ x &= 2.41 \end{aligned}$$

solving for the constant K

$$\begin{aligned} 5 &= K 11.1^{2.41} \\ 5 &= 332 K \\ K &= .0150 \end{aligned}$$

and the final equation for the candle power is

$$cp = .0150 \times w^{2.41}$$

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In the same way, the candle power may be expressed in terms of the voltage and this is found to be

$$cp = 334 \times 10^{-9} E^{3.68}$$

This formula checks precisely with the one used in the engineering department of the General Electric Company at their lamp works, Harrison, N.J.

The horizontal distribution curve of a lamp with its filament mounted as is the modern tungsten is nearly a circle. This is not true, however, in the case of vertical distribution and this curve is shown, Figure III. As will be noted, the tip candle power is only about 23 per cent of the horizontal.

Life Tests.

The results of the life tests were very surprising. The lamps upon the test under [ideal](#) conditions, namely, no vibrations and constant voltage, had only an average life of 460 hours, while every one of those upon the [shock](#) test are still burning at the present time, having been burned 300 hours. In order to make the test still more severe, the lamps were subjected to vibrations without voltage being impressed, and as yet, not a filament has broken, the total time being 400 hours. It was impossible to give more time to these lamps as was done for those under ideal conditions, for the reason it was thought unadvisable to leave the motor, which gave the vibrations, running over night.

The curves have the same general form for the two conditions but the variations are far more great for the lamps which were upon the shock test. The reason for this is that the vibrations were so severe as to shake parts of the filament together thus giving a partial short circuit, causing great variations in candle power.

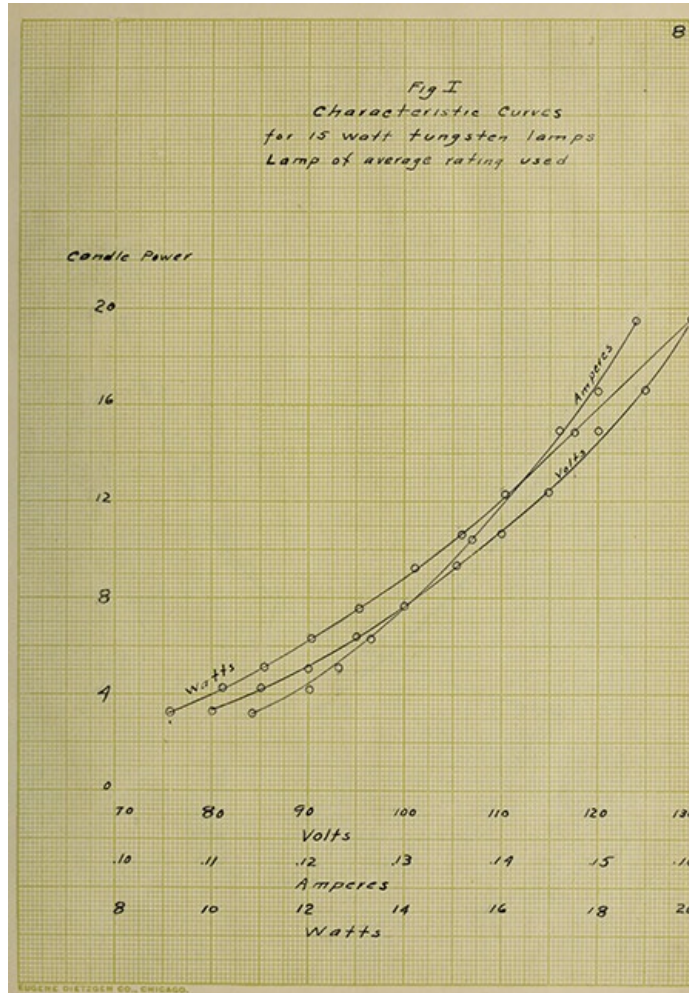


Fig I

*Characteristic Curves for 15 watt tungsten lamps
Lamp of average rating used*

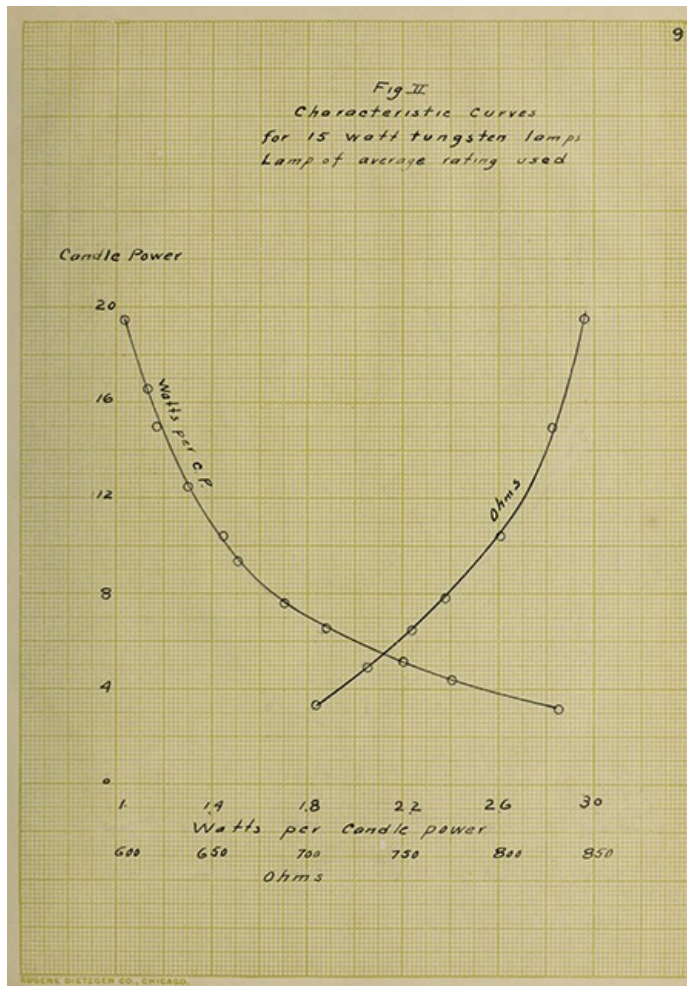


Fig II

Characteristic Curves for 15 watt tungsten lamps
Lamp of average rating used

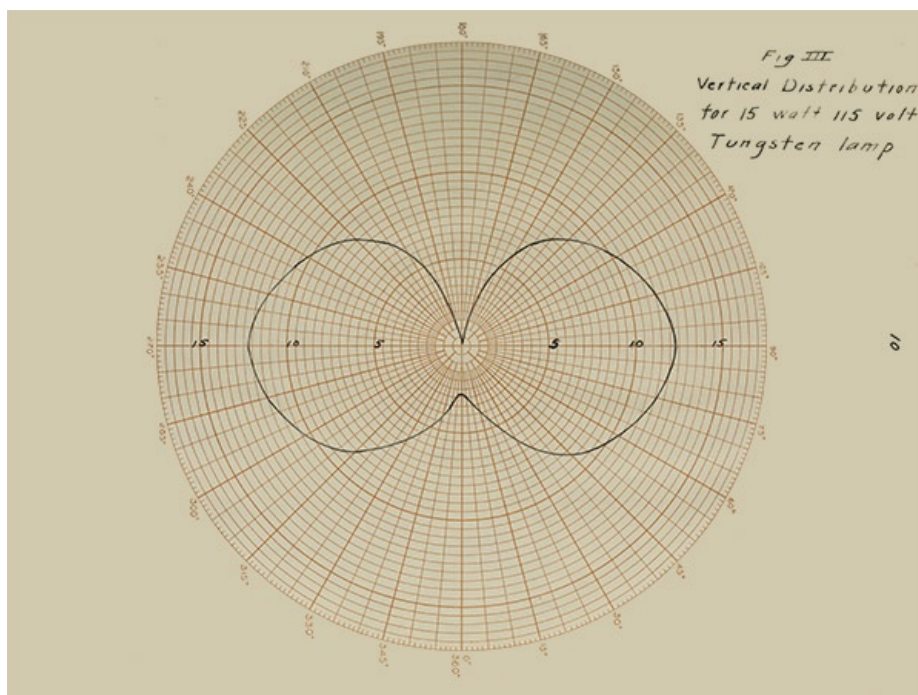
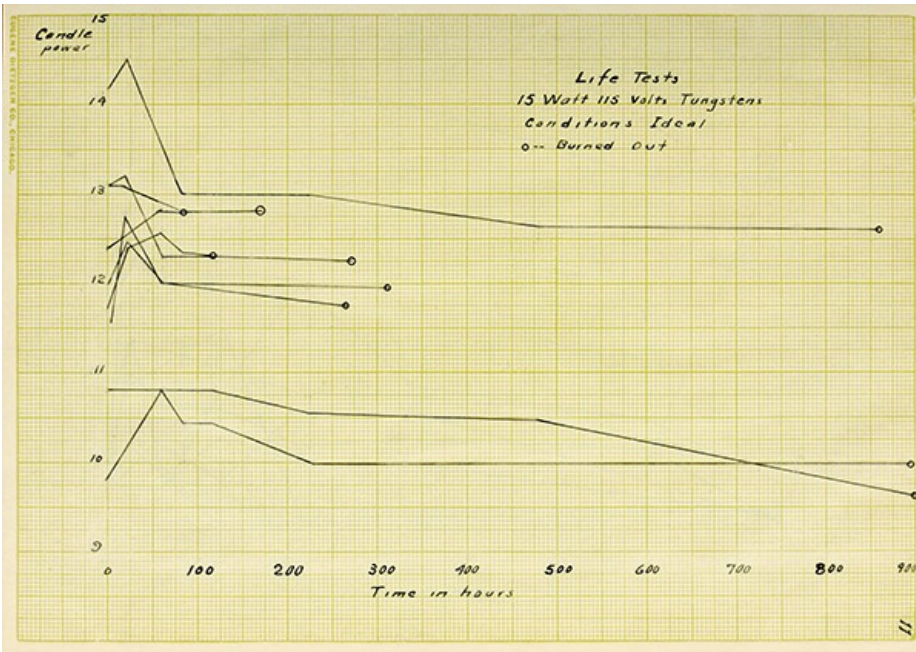
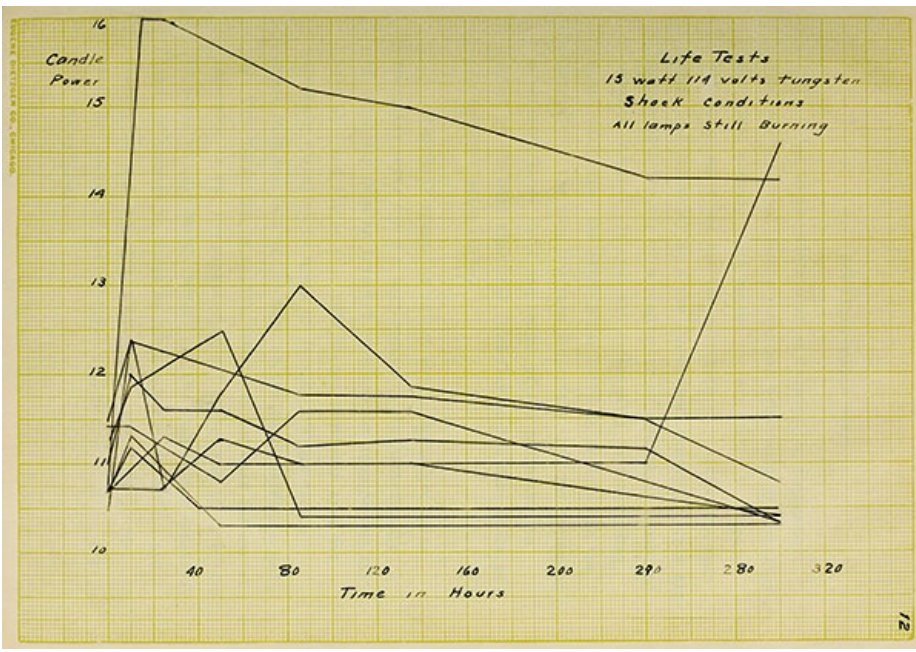


Fig III

Vertical Distribution for 15 watt 115 volt Tungsten lamp



Life Tests
15 Watt 115 Volts Tungstens
Conditions Ideal
o—Burned Out



Life Tests
15 watt 114 volts tungsten
Shock Conditions
All lamps still Burning

Owing to the absence of an integrating photometer, the mean spherical candle power has been found by Kennelley's graphical method. This method is very simple as compared with Rousseau's and has the advantage of yielding the mean spherical intensity as a one dimensional quantity. This dispenses with the use of a planimeter or equivalent measuring surface device. It consists essentially in determining graphically from the given polar curve an evolute and the involute of the same and then projecting this involute upon a vertical line. Half the length of the projection is equal to the mean spherical intensity to the same scale as the original polar curve.

Figure IV shows the method and is explained thus: The polar curve O A H B corresponds to the distribution of intensity from an inverted incandescent lamp having its base at V and tip at V'. This is not precisely true but the only variation to speak of is that the tip candle power does not fall off so much as the curve between B and O. This variation is slight, however. The mean horizontal intensity is OH, the diameter of the circle, and in this case is equal to 12.4 candle power. In the diagram the construction is adapted to zones of 30° and the radii of the midzones found i.e. at +75°, +45°, +15°, -15°, -45° -75°. These are marked by dotted lines O t, O s, O r, O r', O s', O t' respectively.

With radius O r and center O, the arc hra is described through an angle of 30°. The radius Oa is drawn at the end of the arc. A distance Ab is measured from a along a O equal to O s, the second midzone radius. With a center b and radius O s, the arc ac is described through an angle of 30° so that bc makes an angle of 60° with the horizontal OH. The line bc is drawn at the end of this arc. From c towards b, a distance cd is marked off equal to Ot, the third midzone radius. With center d and radius O t, the arc ce is described through an angle of 30° so that de makes an angle of 90° with the horizontal OH. The line de is drawn.

The arc ha'c'e' is extended from the horizontal to the vertical beneath in the same manner as above by steps of 30° with centers O, b', and d', and radii Or', OS' and Ot' respectively. The curve ecarr'a'c'e' is now continuous and complete. A vertical line QQ' is drawn through the convenient point H and the points e c a a' c' e' are projected upon the same. The length HQ, is the upper hemispherical intensity and the length HQ' the lower hemispherical intensity. Their arithmetical mean is the mean spherical intensity. Since in this case the upper and lower hemispheres are symmetrical HQ = HQ' = QQ'/2 = mean spherical intensity. By measurement this half length is found to be 3.125 inches and from the scale used this corresponds to 9.67 candle power. The spherical reduction factor for these lamps is, then

$$9.67/12.4 = 78\%$$

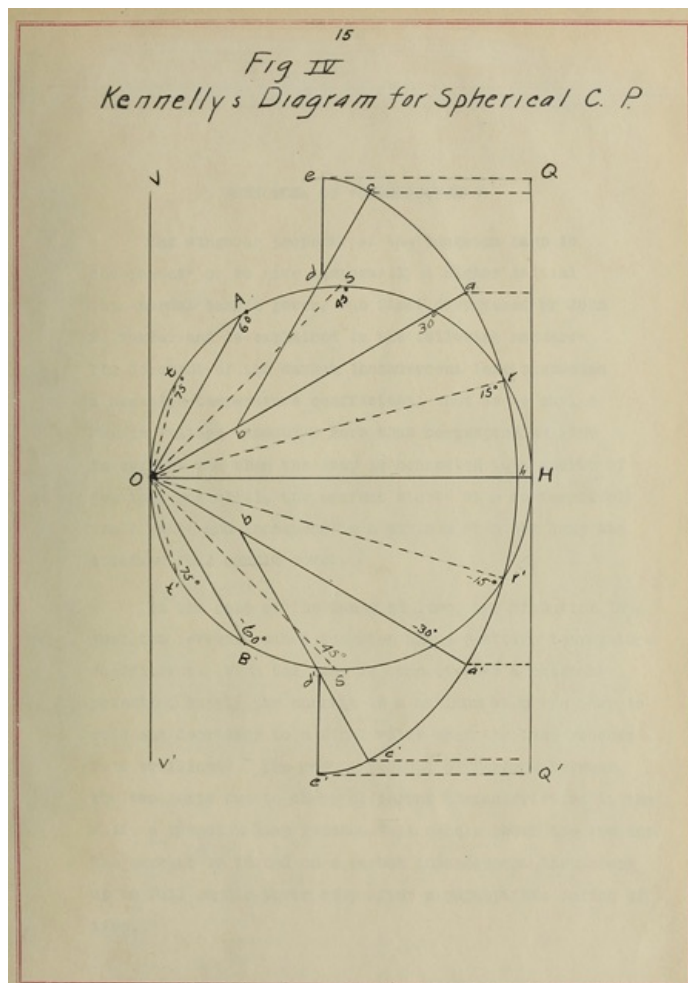


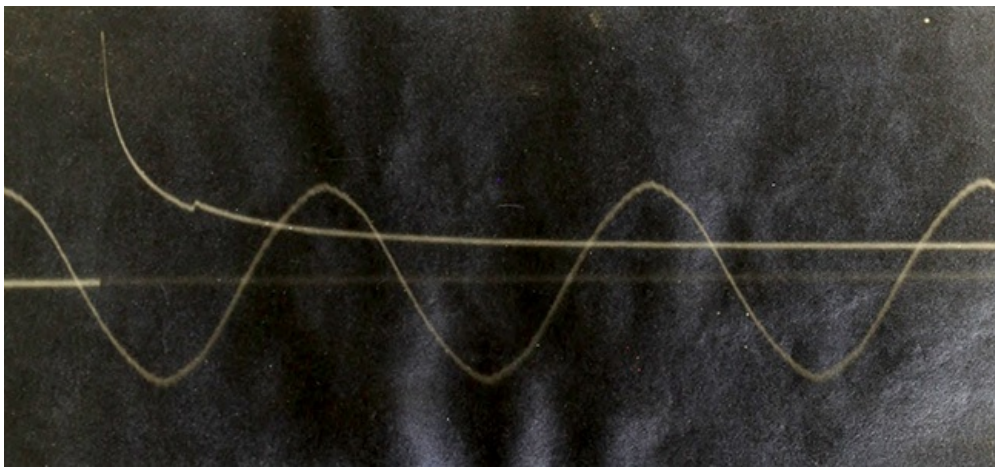
Fig IV
Kennelley's Diagram for Spherical C. P.

The singular property of the tungsten lamp to "overshoot" or to give temporarily a higher initial than normal candle power, was first discovered by John B. Taylor and is explained in the following manner:—The filament of the carbon incandescent lamp possesses a negative temperature coefficient; that is to say, a rise in voltage causes a more than corresponding rise in current and when the lamp is connected to a source of constant potential, the current starts at a comparatively small value and increases to a maximum when the lamp has attained full candle power.

In the case of the tungsten lamp, the situation is just the reverse, since tungsten has a positive temperature coefficient. When the lamp is connected to a constant potential supply the current is a maximum when the lamp is cold and decreases to a final value when the lamp reaches full brilliancy. The most important difference between the two lamps due to these different characteristics is that while a tungsten lamp reaches full candle power the instant the current is turned on a carbon incandescent lamp comes up to full candle power only after a perceptible period of time.

The apparent temporary increase in the candle power of a tungsten lamp was observed early after the lamp was invented but it was generally ascribed to some possible physiological action due to the slow contraction of the pupil of the eye.

The following curve was obtained by means of the oscillograph and shows clearly the rush of current for the first instant after the lamp is turned on. The break in the curve is due to an imperfection in one of the operating switches and has nothing to do with any characteristic of the lamp. The cycle wave was put on merely to obtain the time.



In order to prove that this overshooting occurs, an actual photograph of the intensity has been made. This was obtained by making a box 1' x 1' x 3' absolutely light proof and arranging a lamp inside so that it could be turned on and off at will. A slit, fitted with a shutter, was cut in one end of the box which permitted the light to fall upon a revolving oscillograph film. The film holder was attached to the box with thin metal strips and revolved by means of a small motor. As is seen the whole arrangement was nothing more than a large camera.

The following photograph shows the phenomenon quite clearly, point A denoting where the lamp was turned on.

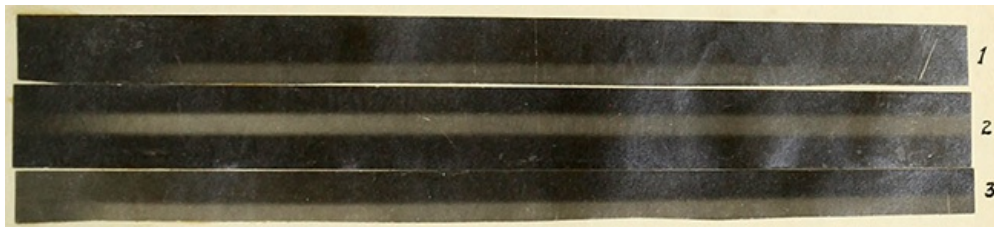


The theory given by Taylor to account for the "overshooting" of tungsten lamps is based on the fact that there is a small amount of residual gas in the lamp, which is attracted to the walls of the lamp when it is cold; and when the lamp is lighted and warms up, this residual gas is driven off lowering the vacuum. With a high vacuum, practically all the energy must be radiated from the filament; conversely, on a lowering of the vacuum, some of the heat is carried away by convection and conduction. When all the heat is carried away by radiation the filament runs at a higher temperature and will give more light.

Another theory is that a cold tungsten filament lamp absorbs and occludes certain gaseous substances from the low pressure space within the chamber. Owing to the presence of these gases the filament shines more brightly when first brought quickly to incandescence, but after the gases have been driven off by the heat, the extra luminescence disappears and can be regained only by prolonged cooling and rest.

Still another theory, and the one that seems the most logical to the writer, is that the increase of resistance accompanying the rise of temperature takes a certain small interval of time so that when the temperature is rising at the rate of thousands of degrees per second, the resistance lags perceptibly. The resistance does not suppress the current as quickly as it should and an extra rush of current and heat energy goes through the filament, raising the temperature above normal, with a corresponding increase in brilliancy.

In order to determine the amount of over shooting, the writer has made photographs as shown below. Number one was made with the lamp under voltage, number two by using normal voltage and suddenly turning the lamp on by means of a snap switch, thereby obtaining the overshooting, and finally number three was made by impressing voltage above normal. The pictures were obtained by using the photographic arrangement as before described. All three prints were made from the same film, that is the three pictures were made upon one film thus insuring the same development and printing for all. The print has been cut merely to allow a closer comparison of the intensities.



It is seen that number three compares favorably with the overshooting as shown by number two and the candle power corresponding was found to be approximately 50% greater than normal. It is not claimed that every lamp will overshoot this amount as the degree of vacuum or other factors of individual lamps may play an important part in this phenomenon. There is no doubt, however, that this strange fact really occurs and is not due to physiological reasons.

In order to prove that the law of resistances, namely, $R = R_0(1 + \alpha t)$ does not hold for the first instance after closing the switch on a tungsten lamp, the following curves have been plotted. Number [V](#) has been taken from the oscillograph record shown in the first part of this paper and shows that about .024 second elapses before the current becomes normal. Knowing the current at any instant as given by this curve, it is easy to find the resistance at the same instant by Ohm's law, the electromotive force being a constant and known value. Curve [VI](#) shows this relation. Curves [VII](#) and [VIII](#) are approximate values and not absolute. Now from the temperature curve, values are taken and substituted in the formula for resistance, $R = R_0(1 + \alpha t)$, the resulting curve being Figure [IX](#). It is seen that curves [VI](#) and [IX](#) do not take the same values at all until after a brief interval of time has elapsed. Curve [VI](#) is absolutely correct, however, as these values have been obtained from the oscillograph record. Consequently, the assumption upon which curve [IX](#) is based must be incorrect for the first .024th of a second and the conclusion is that the law of resistances does not hold. This result tends to strengthen the theory of the lag of resistivity for the "overshooting" of a tungsten lamp.

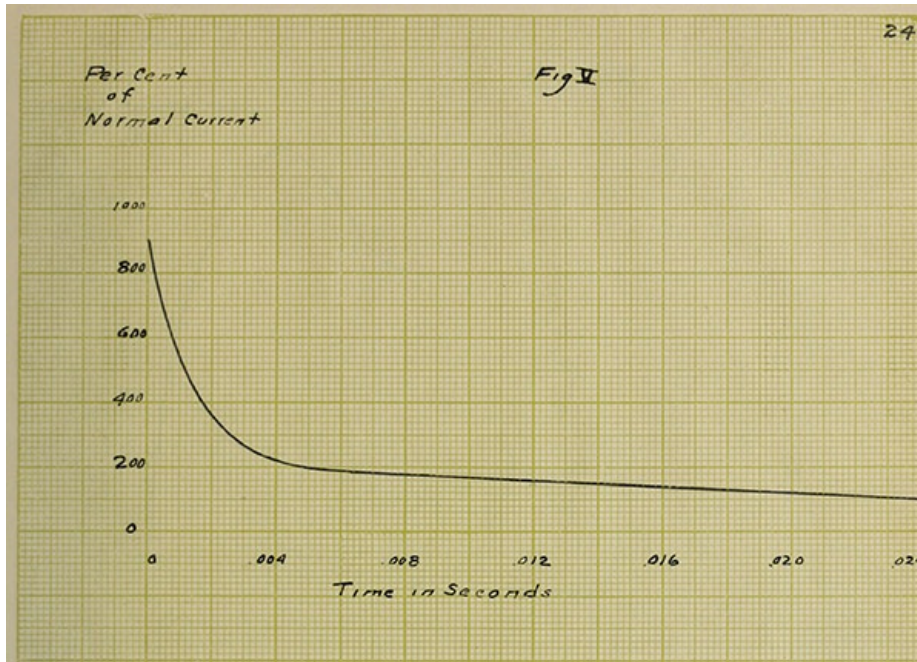


Fig V

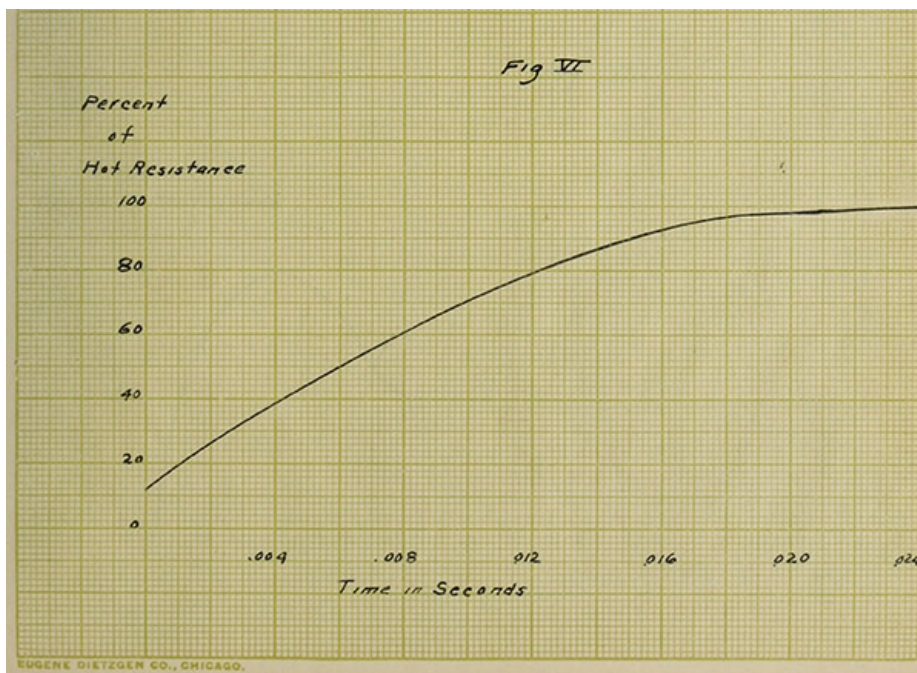


Fig VI

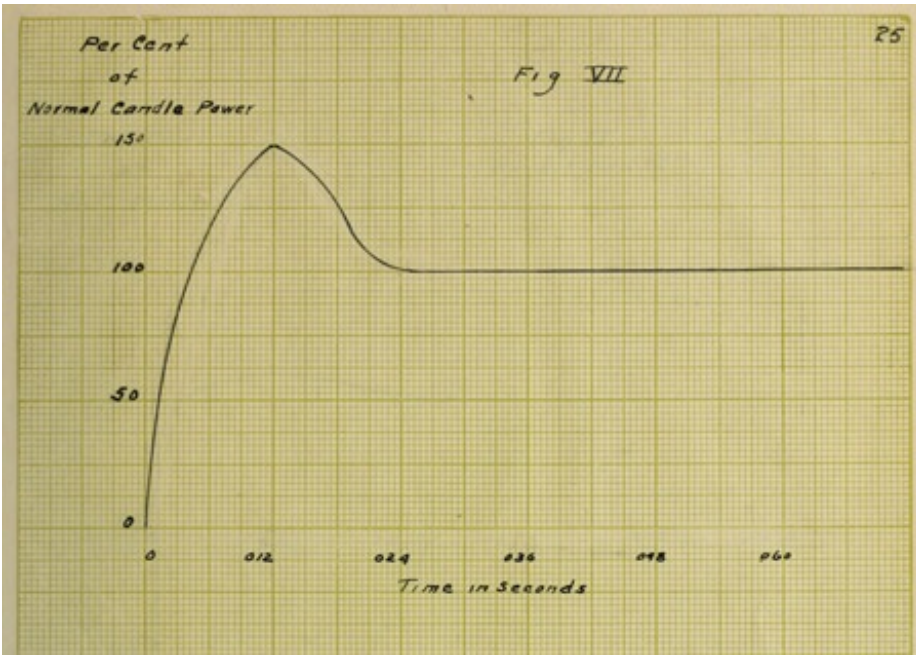


Fig VII

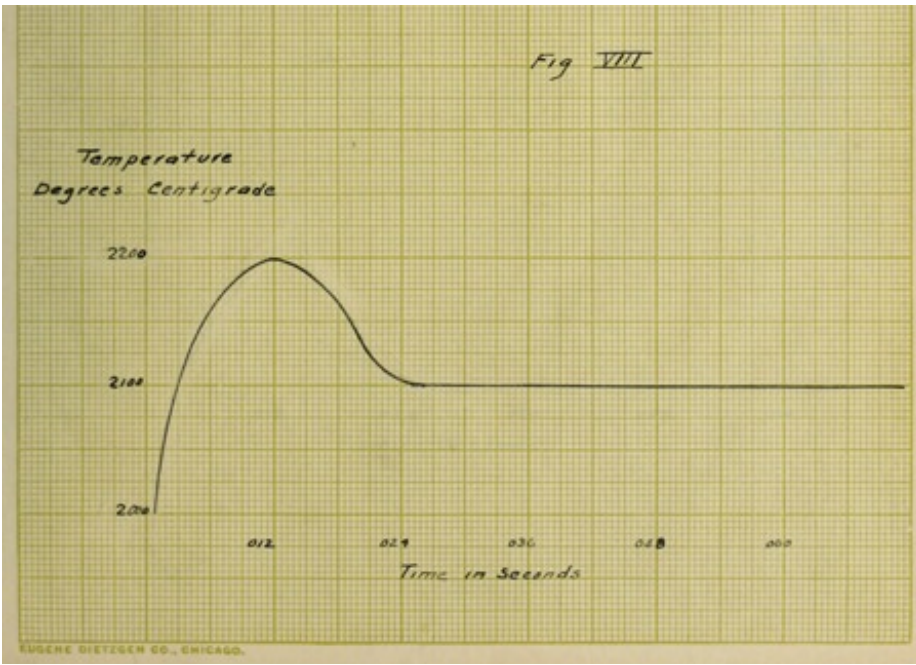


Fig VIII

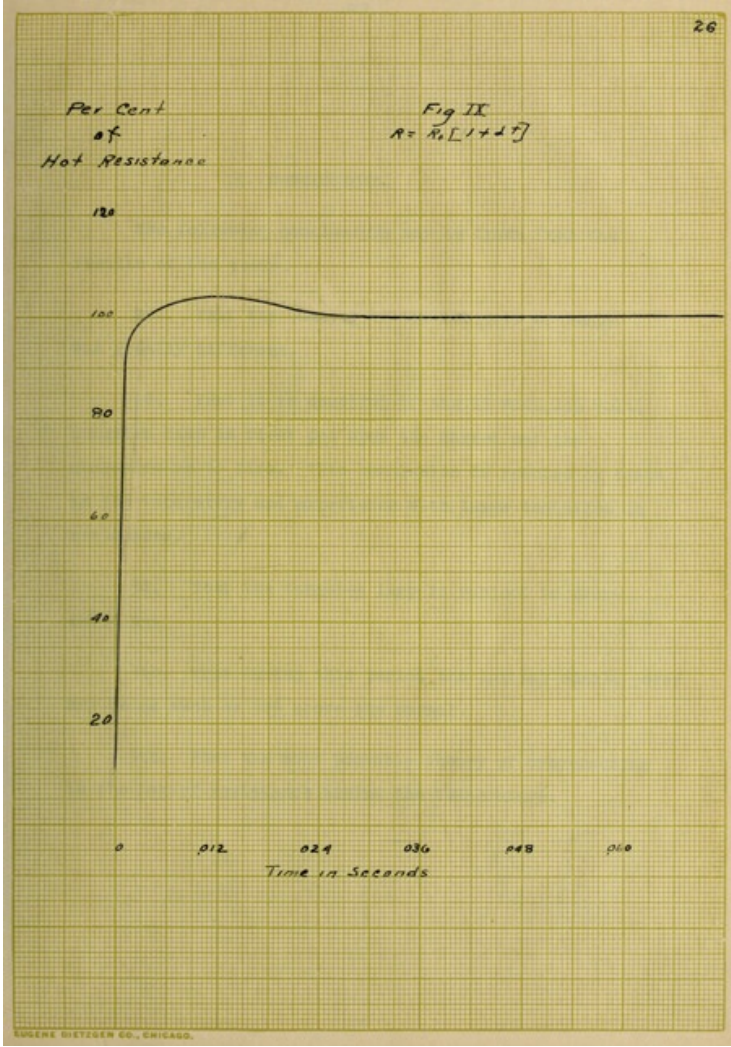


Fig IX
 $R = R_0[1 + \alpha t]$

The following conclusions may be drawn from the results of the tests.

1st, That the quality of the two sets of lamps was greatly different.

2d, That it is doubtful if the 15 watt, 115 volt, tungsten lamp as first put upon the market met the guarantee as to life. This conclusion is reached by tests in the laboratory and experience with lamps installed in residences.

3d, That the tungsten lamp is subject to overshooting.

4th, That during this period the initial candle power may be as much as 50% above the normal.

5th, That the most probable theory of overshooting is the lag of resistance behind the temperature.

TRANSCRIBER'S NOTE

Fractions are represented horizontally using the slash / symbol. The original separated the numerator and denominator horizontally, separated by a _ line.

Punctuation has been normalized. Except in the following cases, variations in hyphenation, spelling and spacing have been retained as they were in the original publication.

Chapter 2:

Lumer-Brodhum photometer → Lummer-Brodhun photometer

Chapter 4:

What appear to be hand-drawn primes in the text have been confirmed as: The arc ha´ce → The arc ha´c´e´.

e c a a´ c e´ → e c a a´ c´ e´

Figure IV

There are two points b radiating from point O. The lower is likely to represent b´.

Chapter 5:

inportant difference between → important difference between

*** END OF THE PROJECT GUTENBERG EBOOK THE FIFTEEN WATT TUNGSTEN LAMP ***

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