

LIFE TESTING OF INCANDESCENT LAMPS AT THE BUREAU OF STANDARDS

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I. INTRODUCTION

The first edition of "Standard Specifications for the Purchase of Incandescent Electric Lamps,"¹ issued in 1907, was the result

¹ These specifications are issued by the Bureau of Standards as Circular No. 13, which has been revised from time to time and is now in the seventh edition.

of concerted action on the part of the Federal Government departments, representative lamp manufacturers, the Electrical Testing Laboratories, and the Bureau of Standards. The purpose of these specifications was to establish such standard methods of initial inspection and life testing as would permit their adoption by the Government and make them available to the general public; so that all purchasers of incandescent lamps, by including these specifications in contracts, might realize the benefits of their use.

Application of these specifications necessitates careful initial inspection and reliable life tests. The specified life-test procedure is so exacting and the quantity of lamps to be tested on any considerable contract so large that the purchaser, unless his facilities for testing are complete, must of necessity refer at least the life-test work to some reputable testing laboratory. It was, therefore, the natural outcome that the Bureau of Standards should be sought and recognized by departments of the Government as the authority on life tests. Initial inspection is so closely related to life-test procedure and its efficiency so pronounced in the effect on the results of life test that the Bureau, almost of necessity, undertook this part of the work as well.

The design of a life-test installation was therefore begun early in 1908. This was developed by Messrs. E. P. Hyde, F. E. Cady, C. F. Sponsler, and H. B. Brooks, under the direction of Dr. E. B. Rosa, chief of the electrical division, which included the photometric section. A lamp inspector was appointed in July and the plant was put into operation in October of the same year (1908). About this time Dr. Hyde and Mr. Cady left the service of the Bureau and the work has since been carried on and developed mainly by the authors of the present paper, under the direction of the chief of the electrical division.

The whole life-test equipment was originally installed in the mechanical building which houses the power plant of the Bureau. In 1913 the life racks, transformers, and photometric apparatus were removed to two adjoining rooms on the third floor of the new electrical building which was then nearing completion. Although some parts of the equipment are differently arranged in the new building, the general plan has remained the same as originally designed.

The introduction of new classes of lamps, however, rendered it advisable to make considerable changes in the original photometric equipment and in the details of the method of testing. These changes have been made from time to time by those who have been most intimately associated with the work. The equipment as it now stands and the present method of the Bureau's life-testing procedure in all its details are, therefore, the result of a gradual development in which various persons have been of assistance.

From the beginning the magnitude of the work of inspection and life testing has been constantly increasing year by year in consequence of the natural growth of the Government's purchases of incandescent lamps. Fortunately, however, the quality of the lamps supplied has, in most cases, been fairly uniform and also above the requirements of the specifications, so that full and reliable data on the lamps supplied by each manufacturer have been obtained by submitting to life test a yearly total of not over 5,000 lamps which represent about one and a quarter millions of inspected lamps.

Since inspections and tests are made primarily for departments of the Government, outside tests are accepted only "when special circumstances make the test of more than usual importance." A specified fee is charged for work of this kind.²

In the following description of apparatus and methods of life test an attempt is made to indicate the essential features of this work and the manner in which the testing is at present actually conducted.

II. PURPOSES OF A LIFE TEST

1. GENERAL

A life test may be run for any one of several reasons. For example, a manufacturer who desires quick results in order to test the effect of some modified construction or change in material may choose to burn the lamps selected at a voltage greatly in excess of that employed in normal operation, thus causing the lamps to fail in a few hours. Unwarranted confidence is sometimes placed in tests of this kind for other purposes, and

² Fees for Electric, Magnetic, and Photometric Testing; Bureau of Standards Circular No. 6, p. 26; 1914.

attempts are made to evaluate life at normal voltage from the test results, whereas no known constants for these life corrections will apply in all cases. Although relative results may be of some value, they often point to conclusions not at all in agreement with those which might be drawn from a test at a voltage corresponding more nearly to rated efficiency.

Comparative tests of greater value may be run at or near normal operating efficiency, even on a line of uncertain voltage regulation, by placing both tests side by side on the same circuit. However, the voltage applied to the lamps of each test must be such that the average efficiency of the two groups is the same, or, if differently rated and burned at one voltage, correction factors must be applied to reduce the test results of one group to their equivalent life at the efficiency of the other group. In all cases the initial (test) efficiency must be known, if test results are to be correctly interpreted. It should be emphasized that relative results only are obtained by such a test, unless the voltage regulation is that indicated in the specifications under which the lamps are tested.

In contradistinction to these rough tests are those in which actual values of life at normal efficiency are obtained for any group of lamps. This necessitates great care in initial rating and constancy of voltage at which the lamps are operated on the life test. By choosing test efficiencies within a range through which factors for life correction have been fully established, the time necessary to complete the tests may be materially shortened. Life tests at the Bureau of Standards are of this kind.

2. SPECIAL PURPOSES OF BUREAU OF STANDARDS TESTS

Although the chief concern of departments of the Government in connection with tests under Standard Specifications is to secure reasonably prompt delivery of lamps which meet the specified requirements, a consideration almost equal in importance is the determination from the life tests of the relative standing of the various manufactures as regards quality of output. The relative quality thus determined is referred to and given due weight in deciding upon future awards of contract.

The evaluation of a lamp life to as high a degree of accuracy as is possible in testing a large quantity of lamps has no doubt guided the manufacturers to some extent in their improvements of efficiency ratings, notably in the tungsten lamp. Consequently manufacturers and purchasers receive all available service and assistance not only from the actual test results but also from conclusions drawn therefrom.

III. SELECTION OF LIFE-TEST LAMPS

The Standard Specifications, in accordance with which all Bureau tests of lamps for Government are made, recognize the importance of a proper selection of samples for life test. It is assumed that no lamp can accurately represent the life of a group unless it accurately represents the group in other respects. Hence, great care is exercised in the selection of the samples for life test, and no sample is taken unless the lamps have first passed the prescribed initial tests.

These initial tests are made by Bureau inspectors³ at the factory of the manufacturer, and regular factory apparatus is used. Such testing equipment as is required in the work of inspection is usually assembled in an inspection department, so that factory work is not interfered with. In the larger factories, where initial tests under specifications are made for a number of purchasers, certain operators are employed most or all of the time in the inspection department. It is their duty to render the inspectors such assistance as may be required in making initial tests. Besides one or more photometers, this department contains vacuum test equipment, special sockets supplied with current for lighting up the test lamps, and, in factories manufacturing tungsten lamps, racks for seasoning or "aging" the lamps selected. This last-named equipment has been introduced as required by Standard Specifications, because of the new process of exhaust, which produces a ductile filament, not, however, stable in its electrical characteristics; so that a certain amount of burning is necessary before the current and candlepower reach values sufficiently steady for accurate measurement.

³ One inspector is employed continuously and another is sent out to assist him when necessary.

The quantity of lamps selected for initial tests is specified as 5 per cent of the total of a lot including only lamps of the same size, class, and voltage range, and not less than 10 lamps from any one lot. The number of lamps to be included in a lot is left to the judgment of the inspector.

The lamps must conform to certain specified requirements as regards bulbs, bases, filaments, and vacuum. Lamps which pass these requirements are then run on the photometer, and in determining their acceptability tables of allowable limits of watts and candlepower, or of watts per candle, as given in the specifications are applied. In calibrating the photometer for these tests the inspector uses standards which have been certified by the Bureau for candlepower and current. A lot of lamps is accepted if the number of defective lamps on either test is below the specified percentage of the total.

The next step is to compute from the records of the photometric test the mean values of individual groups of test lamps representing not more than 250 lamps from any one lot. The lamp nearest the mean value of each group is selected, labeled, and sent to the Bureau to represent the group on life test.

IV. MEASUREMENT OF LIFE-TEST LAMPS

In order to facilitate the photometric measurements of the life-test lamps and still secure a permanent, accurate, and as nearly as possible automatic card record of each lamp tested, certain modifications and additions have been made to the photometer used in this work at the Bureau. As these features are decidedly special and not found elsewhere, their construction and use are fully explained in what follows, not only that the method of measurement described later may be better understood but also that the equipment may be duplicated by anyone desiring to use it.

1. THE LIFE-TEST PHOTOMETER

(a) GENERAL CONSTRUCTION.—The general construction of the life-test photometer is shown in Fig. 1 (frontispiece). A Lummer-Brodhun contrast photometer head is mounted upon a movable carriage between the test lamp and comparison source, the distance between the last two mentioned being 250 cm. The comparison

lamp, a 100-watt tungsten, is placed in a mirror-backed box fronted by a ground-glass window. This window presents an approximately uniform illuminated surface to the photometer, so that the glass plate acts as the effective light source and is so considered. The mirrors within the box are employed to increase the illumination of the window to a practical working value, the effective area of the window being adjusted by means of a variable diaphragm or shutter,⁴ this adjustment being used in calibrating the photometer. By the screening system used stray light is so effectively excluded from the photometer screen that measurements are made in a curtained booth about 8 feet high under conditions which might be defined as approximately "semidaylight."

The standard lamp socket may be rotated in a direction depending upon the position of a knee switch which reverses the current in the armature of the motor, so that lamps may be rapidly turned in or out of the socket and may be rotated during measurements.

Current and voltage leads are joined to the lamp rotator by means of mercury cup connectors. Storage battery current is used in all measurements and available line voltage is adjusted by means of end-cell switches.

(b) INSTRUMENTS AND CANDLEPOWER SCALES.—Current through the standard or test lamp is read on a millivoltmeter connected across a separate shunt. Standard or test lamp voltage is read on a Brooks deflection potentiometer.⁵ On this instrument the balanced portion of the emf is read from the dial which is arranged in steps of 2 volts. The unbalanced portion produces current in the galvanometer circuit, with consequent motion of a pointer over a scale calibrated in 0.1 volt divisions through a range of 1.5 volts above and below the dial setting, so that 0.01 to 0.02 volt is the smallest readable deflection, and the precision of any setting is within these limits. In practice a null method is used and voltages corresponding to dial settings are chosen in the measurement of all test lamps. Certain modifica-

⁴ This arrangement of the comparison lamp and of a special resistance, described later, were introduced by Ives and Woodhull, who, for a short time, were associated with this work. See this Bulletin, 5, p. 555.

⁵ Brooks, H. B., A New Potentiometer for the Measurement of Electromotive Force and Current, this Bulletin, 2, p. 225; 1906.

tions described later have been made in the connections of this instrument to facilitate the convenient handling of large quantities of lamps.

Several candlepower scales are mounted on a brass drum which fits within the front tube of the track. The normal scale is used when the photometer receives unmodified light from both test and comparison lamps. The choice of other scales depends upon the opening of the sectored disk⁶ or the transmission of the glass screen used and upon whether these auxiliaries are used on the test or on the comparison side of the photometer. In routine

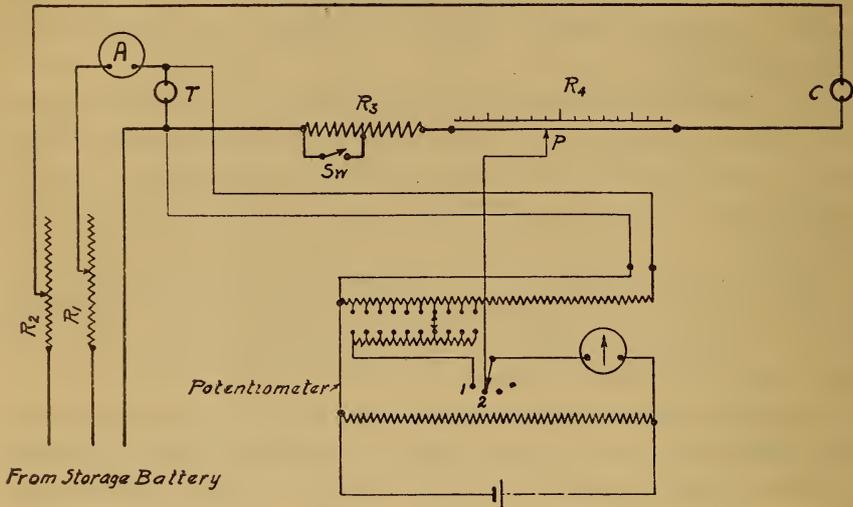


FIG. 3.—Wiring diagram of the life-test photometer

work these scales are used only in calibrating the photometer, because the equipment installed eliminates all reference to actual values on the scales.

(c) WIRING AND SPECIAL RESISTANCES.—As shown in Fig. 3, the test and the comparison lamps are wired in separate circuits in order to permit a wide voltage range on the former without affecting the voltage on the latter. In the comparison lamp circuit, besides the adjustable rheostat R_2 , there are two special resistances designated by R_3 and R_4 , respectively. The purpose of these special resistances is to maintain the comparison lamp

⁶ For all work on this photometer an adjustable sectored disk is used.

at certain definite colors and still permit a precise calibration of the photometer in terms of the group of standards used without making tedious experimental adjustments of resistance.

With the resistance R_3 all in circuit the comparison lamp operates at the color of carbon test lamps. With a fixed amount of R_3 short-circuited by the switch SW , a color used in the measurement of tungsten lamps is obtained. When the standards are operated at the same color as the test lamps, a color match with the comparison lamp is obtained by placing a blue glass screen (the transmission of which need not be known) on the comparison side of the photometer. This is done in order that the comparison lamp may be operated at a comparatively low efficiency, and thus prolong its useful life. In case it is desired to run test lamps at an efficiency higher than that which would be safe for the standards, a glass screen of known transmission must be used with the comparison lamp while measuring the test lamps, but in calibrating the photometer the screen is replaced by the sectored disk so set that the percentage opening is equal to the transmission of the screen. In this way the standards are operated at the unmodified color of the comparison lamp and the test lamps at any desired color for which a color screen of the proper density for color match with the comparison lamp is selected.

The potentiometer button 2 , to which the galvanometer is switched in setting the comparison lamp, is connected to contact P on the slide-wire resistance R_4 , which will be described presently. In the position shown it is evident that the drop from P across the portion of R_3 in circuit is measured. This drop is proportional to the current in the comparison-lamp circuit, and hence by a proper choice of resistance R_3 (which is large in comparison with R_4) the exact current in the comparison lamp for carbon color is obtained. As the voltage on the standards or test lamps is set with the switch lever on button 1 , a check can be kept on the current in the comparison lamp without disturbing the potentiometer setting by simply switching the lever to button 2 . Any necessary adjustment in the current is made by means of resistance R_2 to bring the galvanometer pointer back to zero.

In calibrating the photometer the adjustment of the comparison source is easily made to within 1 or 2 per cent in candlepower by means of the adjustable shutter on the ground-glass window. The final adjustment is made by moving contact P along the slide-wire resistance R_4 a distance corresponding to the desired small change in candlepower as read from a scale of candlepower differentials placed under the wire. The changes of current produced by moving P are small, so that the changes in color of the comparison lamp thus produced are entirely negligible. Ives and Woodhull⁷ made use of an adjustable resistance, but the null method made possible by the modified potentiometer connections and the calibrated slide-wire resistance just described was introduced later.

(d) THE WATTS-PER-CANDLE COMPUTER.—Two sets of special scales are used in connection with this photometer. One set is used in computing watts-per-candle from the observations while the other set is used in connection with a recording device. The wpc computer, which operates on the principle of an ordinary slide rule, consists of an ampere scale and a wpc scale both logarithmic and calculated on the same base.⁸ These are placed parallel to the photometric axis between the photometer head and the carriage, the wpc scale (showing white in FIG. 1) being attached to the carriage so as to move with it.

The design of the computer is based upon the fact that a logarithmic scale may be constructed which practically coincides with the candlepower scale over a range extending from one-half to double the candlepower reading at the middle of the scale. The base of such a logarithmic scale for a 250 cm photometer is 71.25 cm, and the maximum differences of a scale so constructed from the true candlepower scale, the middle division of which is 20 candlepower, are only 0.08 cm, corresponding to about 0.25 per cent in candlepower and occurring at approximately the 14 and 28 candlepower divisions. These differences, even at the points of maximum value, are entirely negligible for the purposes of this photometer and the advantages gained by employing the logarithmic scale fully offset the small errors introduced.

⁷ See note 4, p. 611.

⁸ The base of a common logarithmic scale is the distance from 1 to 10, 10 to 100, etc., on the scale.

The two parts of the computer are logarithmic scales constructed in this manner, but the divisions are labeled amperes and wpc, respectively, instead of candlepower.

Now, it is evident that, with the photometer set to a given candlepower, the ampere scale may be moved horizontally to a point where for a given voltage the corresponding wpc will appear under any chosen value of current (which then corresponds to the wattage), and that after this setting the correct wpc value will appear under the corresponding current at all points of the scale. Now, if a lamp is run at this same voltage and the photometer is moved to the point of balance the correct wpc will still appear under the observed current, because the wpc scale attached to the photometer carriage has been moved in its relation to the ampere scale by a distance corresponding to the change in candlepower. The ampere scale must be reset for every change of voltage, but by proper grouping of lamps a large number may be run in succession at one voltage, so that these changes are infrequent during any single run.

(e) THE RECORDING DEVICE.—The recording device consists of a stamping magnet, a cylinder carrying a number of scales, and a car for holding the record cards. The magnet and cylinder are attached to the photometer carriage, and therefore move with it. The cylinder is mounted normal to the photometric axis and carries three logarithmic scales running parallel to its length, one being an hour scale, the other two being wpc scales for use in measuring tungsten and carbon lamps, respectively. The magnet is supported by a rod placed parallel to the cylinder, so that the pointer carried by the magnet may be set at any division on any one of the three scales, the desired scale being presented by turning the cylinder.

The car may be moved on a track parallel to the photometric axis but is held at any one of a number of nearly equally spaced points by means of a pin placed in a corresponding hole in the track. The distance between any two adjacent holes corresponds to half the distance from 100 per cent to 80 per cent candlepower as read from the true candlepower scale. These holes are labeled with two series of the same letters, one series being printed in red, the other in black, the letters of the red series being placed

two spaces nearer the comparison lamp than the corresponding letters of the series in black. The use of these letters will be described presently.

The observations are recorded as points stamped on plain white cards approximately 12.5 cm by 20 cm, there being one card for each lamp. (See Fig. 4.) These cards are placed in the car with their long dimension normal to the photometric axis and therefore parallel to the scales on the cylinder. Now,

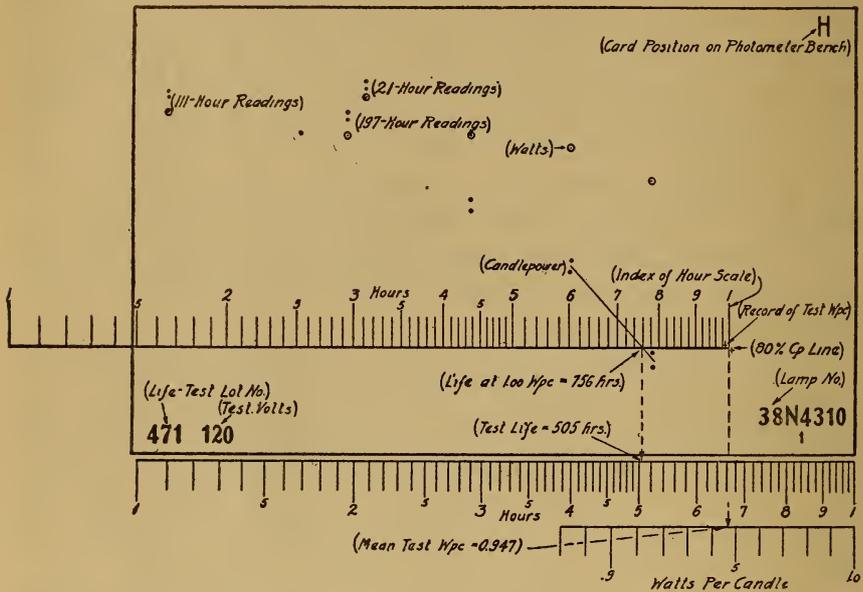


FIG. 4.—Completed test record on a lamp card showing the scales used in placing the record points and in evaluating corrected life

This lamp, a 40-watt, 110-volt, tungsten, was tested at 0.947 wpc and had a life of 505 hours which is equivalent to 756 hours at 1.00 wpc. It was rated at 1.05 wpc by the manufacturer and the life specified was 1,000 hours which is equivalent to 697 hours at 1.00 wpc. Hence, the life of the lamp was $756 \div 697 = 108.5$ per cent of the life required by the specifications. (For further explanation, see p. 618)

it is evident that the short dimension of the card may be looked upon as a candlepower scale and the long dimension as an hour scale or a wpc scale, depending upon which of these two quantities is to be measured and recorded. The position for the card on the photometer is so chosen at the initial measurement that the candlepower record will be made sufficiently high to permit all values during the life of the lamp to fall on the card. This is regarded as the normal position of the card and is designated

by the corresponding *black* letter which is then written on the card. The card is placed in this position during all but the initial measurements, the reason for this exception being given in the following section.

The two most important quantities to be recorded are the initial (test) wpc and the life. The latter is defined as the number of hours required for a lamp to reduce to 80 per cent of its initial candlepower, or to burn out, if within that period. Now, it is evident that, so far as making the record is concerned, motion of the card toward higher candlepower on the photometer is equivalent to moving the photometer in the opposite direction. If, therefore, during the initial measurement of candlepower the card be set, not at its normal (*black* letter) position, but at that designated by the corresponding *red* letter, the record point of the observed candlepower will fall at a position corresponding to 80 per cent of the value observed. This point therefore establishes on the record the limiting line of life as defined by the specifications.

As the record of the initial measurement does not include the element of time, it may be made at any point along the 80 per cent line. Hence, if the stamping magnet be set at the point on the wpc scale (which scale for tungsten lamps is reproduced under the card in the figure) corresponding to observed initial wpc, not only 80 per cent of the initial candlepower but also the initial wpc as well may be recorded by the same point. To distinguish these initial points from the rest of the records, they are stamped in *red* (indicated by + in the figure) while all the others are stamped in *black*. For all but the initial measurements the card is set at the *black* letter position and the magnet is set at a point on the hour scale (which scale is also reproduced under the card in the figure) corresponding to the total number of hours the lamp has burned. The candlepower-hour record points are stamped in succession across the card as many times as necessary, depending upon the life of the lamp, the hour scale reading for each succeeding series being ten times the value it had in the series next preceding. The complete record thus obtained on any card graphically represents the performance of the corresponding lamp and the actual test life is indicated by the point

of intersection of the curve of candlepower performance with the 80 per cent candlepower line.

So far as obtaining a record is concerned, any scale might have been adopted for use on the cylinder in recording test life and initial wpc, but the scales here employed have been so chosen in respect to their relative lengths and relative position on the cylinder as to permit the evaluation of corrected life from test wpc to rated wpc directly from the card record without computation or reference to tables of factors. This arrangement was based upon the following considerations.

It has been shown that within certain limits the relation between life and wpc may be expressed by the formula,

$$\text{Life ratio} = (\text{wpc ratio})^m \dots \dots \dots (1)$$

in which m has been found to have a value of about 7.4 for tungsten lamps and 5.83 for carbon lamps. From equation (1) is derived

$$\log \text{ life ratio} = m \log \text{ wpc ratio} \dots \dots \dots (2)$$

analogous to the equation

$$y = mx \dots \dots \dots (3)$$

which is the equation of a straight line. Hence a logarithmic hour scale and a similarly constructed wpc scale with a base equal to m times the base of the hour scale may be used together as a slide rule for making life corrections from one efficiency to another. Life in hours on the one scale is set opposite the corresponding wpc on the other, and life at any other wpc, not exceeding the limits through which m has a constant value, is read by referring to the corresponding wpc division.

The hour scale on the cylinder of the recording device was plotted to a base of 20 cm (equal to the approximate length of the record cards) with divisions from 1 to 10, as in all slide-rule scales, and hence the base taken for the wpc scale for tungsten lamps was $7.4 \times 20 = 148.0$, and for carbon lamps, $5.83 \times 20 = 116.6$.

Life requirements in the specifications are expressed in hours at rated wpc, being at present 1,000 hours for tungsten lamps and from 120 to 450 hours for carbon lamps, depending upon the size. In order to facilitate the test of tungsten lamps, they have been burned at from 0.90 to 0.95 wpc but carbon lamps have been

tested at or near their normal rating. To avoid complications in the recording device and occasional changes to correspond to changes which, from time to time, are made in the rating of lamps as the art of manufacture improves, it was considered best to arrange for the correction of test life values to their equivalent at a certain chosen wpc for each class of lamp. Accordingly 1.00 wpc was chosen for tungsten lamps and 3.05 wpc for carbon lamps and by means of equation (1) the life requirements of all sizes of each class at rated wpc were reduced to their equivalent at the corresponding chosen wpc. These values then are referred to as the required life instead of those given in the specifications and the life of any lamp, or of any group of lamps of the same size, is expressed in per cent of the required life. (See explanation under Fig. 4.)

The logarithmic hour and wpc scales constructed as above described were then so placed on the cylinder that the 1.00 wpc division of the tungsten scale was in line with the 1000-hour division of the hour scale, as shown in Fig. 4, and the 3.05 wpc division of the carbon scale in line with the 450-hour division. The wpc points on the card are thus recorded on a logarithmic scale and in a definite relation to the hour scale. Now, if the 1000-hour division of the scale in the case of tungsten lamps or the 450-hour division in the case of carbon lamps be taken as an index and a duplicate of the hour scale be placed, as shown in Fig. 4, with the proper index on the mean of the wpc points of the record and with its reading edge on the 80 per cent line, the test life, corrected to the chosen wpc, may be read at the intersection of the scale and the candlepower performance curve.

In case a lamp burns out above 80 per cent of its initial candlepower value, a vertical line is drawn across the 80 per cent line at the proper point as determined by the life test log and the hour scale, but the procedure in obtaining corrected life is the same as in the case of lamps which have burned to 80 per cent.

For lamps having other than the specified mean spherical reduction factors, the index may be so chosen that the corresponding difference is made in the corrected life. Certain special lamps, for example, lamps in tubular and round bulbs, are thus evaluated.

(f) FEATURES OF THE RECORD.—(α) *Detection and Compensation of Errors.*—One characteristic of these record points of the initial readings of wpc and candlepower (Fig. 4) is of interest and importance in that it serves as a visual check upon the correctness of the records. Rarely do two observers on the photometer check each other exactly, but the precision of electrical instruments and the constancy of electric lamps during the relatively short time they are in circuit on the photometer are such that the ampere reading is usually repeated to within 0.001. Suppose, now, that at the same current the second observer reads a candlepower value higher than that recorded by the first. The wpc computer will, consequently, indicate a lower value, since the candlepower is higher for the same watts. Referring to Fig. 4, it will be seen that the second point will be placed above and to the left of the first. For a candlepower reading lower than the first, the current remaining the same, the point will be placed below and farther to the right. Suppose, now, that one or other of the ampere readings is in error, the second being appreciably higher than the first. The apparent wpc of the second observation is then higher than it should be, regarding the first as correct, and the effect is to change the slope of the line connecting the two observations. Displacements may occur also in case of errors in transfer to the record card or as combination of errors.

Now it is evident that the equation

$$\text{Watts} = \text{cp} \times \text{wpc} = \text{constant} \dots \dots \dots (4)$$

expresses, for a steady lamp, the condition for correct reading. This is the equation of an equilateral hyperbola. Although somewhat modified by the logarithmic scale of the recording equipment, it is closely approximated in form by correctly recorded points under conditions of constant watts; so that the slope of the line connecting the initial wpc points may be used as an indication of their precision, and any considerable deviation from the correct slope indicates that some error has been made. Any lamps, the records of which, show such deviations are, therefore, rephotometered.

Another interesting feature of the card record of a normal lamp is that the slope of the candlepower-life curve between its last

two points is often very nearly the same as that of the line joining the two initial wpc points; consequently in these cases comparatively large differences in distance between initial points effect no considerable change in corrected life, which may be evaluated with small error from any point in the line connecting the wpc points. Observational errors in initial readings are therefore always compensated for to some extent by the fact that the candlepower-life and initial wpc curves always slope in the same general direction. It is doubtful if any other than this system of photometry and recording possesses these advantages.

(β) *Increased Accuracy in Life Values.*—It has already been stated that in evaluating lamps which have burned to 80 per cent a straight line is drawn between the last two points on the record cards, one of which is above and other below the 80 per cent candlepower line. (Fig. 4.) If this line be transferred to rectangular coordinates it will be found that it is slightly curved, being convex downward toward the life axis. As this is characteristic of a true candlepower-life curve, this method gives, on an average, a closer approximation to the actual time of crossing the 80 per cent line than that obtained by direct interpolation.

2. METHODS OF MEASURING AND RECORDING OBSERVED VALUES

(a) *RATING OF LAMPS FOR LIFE TEST.*—Two methods are in common use in rating lamps for life test. The first distinguishes two voltages, namely, "photometer" voltage, which usually corresponds to rated voltage, and "rack" voltage. Rack voltage is computed from photometer voltage and the corresponding wpc by the characteristic equation expressing the relation of volts to wpc. By this method the lamps are always run on the photometer, both initially and during life test, at photometer voltage. They are operated on life test at rack voltage, which of course corresponds to test wpc within the desired limits. By the second method the lamps are photometered and operated on life test at rack voltage. In the case of vacuum tungsten lamps, the characteristics of which are well known, either method may be used. Advocates of the first method claim advantages for it in the greater certainty of candlepower observations made at or near a color match with the standards. These are no doubt real

advantages, as there is now practically no uncertainty introduced by computations based on well-established values within certain limits of wpc for normal lamps.

The Bureau, however, employs the second method. Although this method was adopted before the characteristics of tungsten lamps were as well known as they now are, it is still used because it introduces no uncertainties due to possible failure of any lamps to conform to the characteristic relations. Although an extra scale for reading rack voltage could easily be added to those above described, thus permitting measurements at photometer voltage, a careful investigation of the possible added advantages thus secured as weighed against a somewhat greater complexity of apparatus and consequent added liability of error would first have to be made if a change to the first method should ever be contemplated.

(b) DETAILS OF A PHOTOMETRIC RUN.—As a Lummer-Brodhun photometer is used, all measurements are made at as nearly a color match as possible. By the method at present in use, the photometer is always calibrated by six tungsten standards selected at random from a much larger group. The values of candlepower and current for the individual lamps of this group, over a wide range of voltage (and color), are tabulated on a card within view of the electrical operator and in what follows these are designated as "certified" values. The comparison lamp is adjusted in current so as to give the proper color to match the lamps to be tested, this being done by simply balancing the potentiometer against the voltage drop across resistance R_3 (Fig. 3), the small adjustment necessary being made by means of resistance R_2 . Switch SW is open or closed, depending upon whether carbon or tungsten lamps are to be measured. The first standard is then placed in the socket and adjusted in voltage to match the modified or unmodified color of the comparison lamp depending upon the efficiency at which the test lamps are to be measured. (See p. 613.)

After the color adjustment, the certified candlepower value of the standard, at the voltage to which adjustment was made, is called off by the electrical operator, and the photometer operator so adjusts the shutter on the ground glass window which fronts the

comparison lamp box that a balance is secured at approximately the certified value as read on the candlepower scale. After this approximate calibration, a stamped record of about ten individual settings is made for each of the six standards. After the observed values of a standard are recorded, the certified value is called off by the electrical operator and, with the photometer set at this point on the scale, this value also is stamped on the card. A copy of a short section of the candlepower scale is used to read off the algebraic differences between the certified and the observed candlepower values. In this manner the difference between observed and certified values of all the standards are determined and the mean difference in candlepower is computed. Correction for this mean difference is then made by moving the sliding contact P of the resistance R_4 (p. 614) the proper number of scale divisions. This necessitates a small adjustment of the comparison lamp current which is now made by means of resistance R_2 . The electrical operator has, in the meantime, compared the observed current with the certified current and determined a mean correction for ammeter readings; or, in case lamps whose ampere readings are considerably different from that of the standards are to be run, the proper ampere standard is selected from a group of seasoned lamps used only for this purpose, and the mean ampere correction thus established is applied throughout the run. The standard check is the last direct reference made to actual values on the candlepower scale.

Having determined by trial the even voltage (e. g., 118, 120, etc.) corresponding to a dial setting on the potentiometer at which the first test lamp falls within the desired range of test wpc, the ampere scale is set to a point corresponding to this voltage. (See p. 615.) Opposite the ampere value called off by the electrical operator is read the test wpc. With the corresponding lamp card so placed that the value to be recorded will be at least two-thirds of the way down the card, the index carried by the stamping magnet is set at the observed wpc, the circuit through the magnet is closed by pressing a button, thus making the record of the wpc and also 80 per cent of the candlepower as a single point in red. The red letter indicating the card position is noted and a card bearing this letter is selected from the file within reach and placed

face down on the photometer bench, the first record card being turned over and placed upon it. As the different lamps are photometered the corresponding lamp cards and position cards are added in regular order. The same voltage is applied to each lamp in succession until one is reached which requires a change of voltage, when the ampere scale is reset to correspond to this voltage. Readings are continued at this new voltage to a point where another change of voltage is required, etc. "Information cards" designating voltage, disk opening, card position, etc., are introduced in the proper place to indicate the changes to be made in succeeding measurements.

The photometer calibration is checked by two or three standards at intervals during the run and the indicated changes of comparison lamp current are made when required (p. 613). After the first run, cards for lamps of the same voltage, disk opening, card position, etc., are grouped together to the best advantage, the extra information cards being removed and filed for future use. The life-test lot number, the voltage, and position letter are then printed or written on each card, and the lamps rearranged for a second run in the order determined by the card positions, thus facilitating the work. After the second run, for which the two operators exchange places, such additional check measurements as are found necessary (p. 620) are made. The lamps are then ready for the life-test racks, where they are burned at the respective voltages found.

After the first period of burning on the life test, the lamps are removed, placed in the proper order and again run on the photometer at the test (rack) voltage. The cards are now set to the *black* letter position (p. 617) indicated on the information cards and on each lamp card, and the stamping-magnet index is placed at the point on the hour scale corresponding to the number of hours the lamps of the lot have burned.

The ampere scale is set as in the initial run, and, after the observed candlepower value is recorded, the photometer is set so that an index on the movable part of the wpc computing device is opposite the observed current value and a record of the position is stamped. As the voltage at every measurement of a given lamp is the same, this record shows the variations in the

watts during the life of the lamp. (These points are surrounded by circles in Fig. 4.)

Measurements are made in this manner after each test life period until all lamps of the lot have crossed the 80 per cent candlepower line or burned out above it.

V. THE LIFE TEST

1. DESIGN OF THE INSTALLATION

At the time when the design of the life test equipment was under discussion, the common method in use elsewhere of setting individual lamps or racks of lamps to a desired test voltage was by means of a resistance in series with each lamp or rack. The disadvantages of this method were apparent, and search was therefore made for an arrangement of equipment which would be free from these disadvantages, but which would still conform to the requirements to be met. An arrangement of auto-transformers proposed by Mr. Brooks was adopted because of its simplicity, convenience, and general conformity to the requirements of life-test operation. Other laboratories have since adopted the essential features of this arrangement which are fully described below.

(a) WIRING AND VOLTAGE ADJUSTMENT.—Referring to the wiring diagram, Fig. 5, which exhibits the essential features of the system, it is seen that alternating current is supplied by the generator to the center of distribution. Auto-transformers T_1 to T_4 supply current to the bus bars at the voltage indicated.⁹ These bus-bars are mounted on the back of the switchboard panel farthest to the right. (Fig. 2, frontispiece.) One terminal of each rack (horizontal row) is connected to the common bus through the secondary of a corresponding regulating transformer B ; the other terminal is connected to a plug hole in this same panel. Hence, to energize a given rack R a connecting cable is plugged from the corresponding plug hole to the bus maintaining the voltage nearest to that desired. The conductors from the switchboard to the racks are of No. 4 wire carried through 10 lines of 2-inch conduit running over the tops of the switchboard and racks to junction boxes from which connection is made to the terminals of the copper rod conductors of the racks.

⁹ No provision has yet been made for low voltage or series burning lamps.

The special autotransformer *ST* maintains voltages of +5, +10, +15 to +50, and corresponding negative voltages on bus bars located on the front of the middle panel. One primary

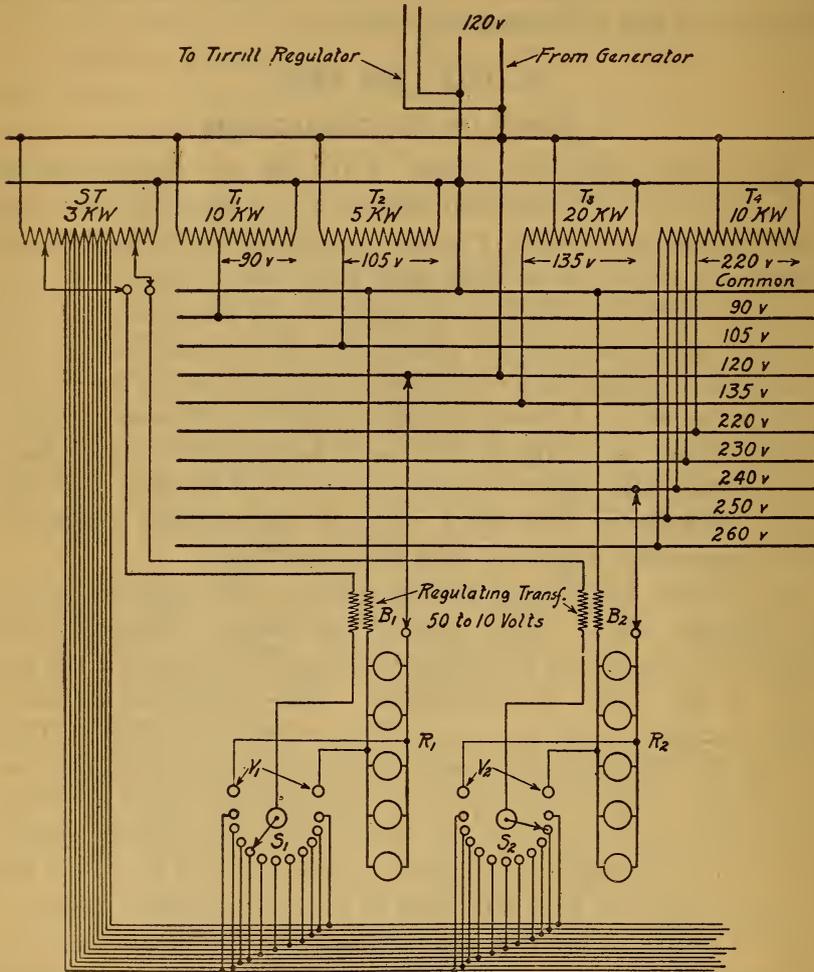


FIG. 5.—Wiring diagram of the switchboard and life racks.

terminal of each of the regulating transformers *B* ends in a corresponding plug hole also on this panel. As the ratio of transformation of each regulating transformer is 5 to 1, it follows that + or - changes of 1, 2, 3 to 10 volts may be made effective

on the rack. Hence, by plugging from the transformer terminal to the proper bus bar on this panel, a second approximation to the exact voltage desired on rack R is obtained.

The other primary terminal of each of the regulating transformers ends in the lever of a corresponding dial switch S located on the left panel of the switchboard. The buttons of each switch are maintained 1 volt apart over a range of 10 volts, by leads from adjacent 1-volt subdivisions of transformer ST , but because of the 5 to 1 transformation in B each volt at the switch is effectively 0.2 volt on the rack. Hence, by properly setting the switch 1, the exact voltage desired is approximated to within 0.1 volt.

The voltage of each rack is adjusted at the switchboard by reference to a portable voltmeter which may be connected to the corresponding pair of binding posts forming the terminals of the potential leads V from the center of the rack. The voltage of a rack is thus adjusted by actual measurement in every case. Each pair of binding posts appears on the corresponding dial switch. As these switches are grouped on a single panel, any number of racks may be quickly set without inconvenience with the voltmeter kept in a fixed position on its stand.

(b) VOLTAGE REGULATION.—A Tirrill regulator, which operates by periodically short-circuiting a resistance in series with the exciter field, maintains the voltage at the center of distribution in the life test room constant to within the limits of plus or minus one-quarter of 1 per cent as required by the specifications. A continuous record of this voltage is obtained on an accurate recording voltmeter located in the dynamo room.

(c) CURRENT GENERATOR AND VOLTAGE TRANSFORMERS.—The generator which supplies current for the life test is a 40-kw, 125-volt, 360 rpm; single-phase, rotating-field alternator, directly connected to the driving engine, the exciter being mounted upon the same shaft. Transformers B (shown back of the switchboard in Fig. 2) are one-half-kw, air-cooled, shell-type; while ST and T_1 to T_4 are oil-immersed, auto-transformers of the capacities indicated in Fig. 5, the relative capacities of T_1 to T_4 being roughly in proportion to the number of lamps usually run at their respective voltages.

(d) **THE LIFE-TEST RACKS.**—The supporting frames of the racks are built up of steel members consisting of vertical end posts of channel section and equally spaced intermediate posts of I-beam section connected by heavy angles to horizontal top and bottom pieces of channel section, the whole being supported by cast-iron feet bolted to the composition (Tileine) floor. Bolted to each side of the vertical members are six equally spaced horizontal strips of asbestos board which support porcelain cleat sockets, spaced on 12-inch (30.5 cm) centers, with soldered electrical connections to copper rods 5 mm in diameter. Midway between each pair of these sockets, which are arranged for burning the lamps in a horizontal position, conducting straps are soldered at one end to the 5 mm copper rods and at the other end to the terminals of porcelain cleat sockets arranged for burning lamps in a vertical position. The long racks (17 feet (5.18 m)) have 31 sockets on each side; the short racks (13 feet (3.96 m)), 23. On a few of the lower racks the sockets for vertical burning are spaced on 18-inch (45.7 cm) centers. The large lamps burned on these racks are thus kept well separated during life test. The total number of vertical sockets is 1200 and of horizontal sockets, 1296.

The eight stacks of racks are spaced 4 feet 10.5 inches (1.49 m) apart, which gives a symmetrical arrangement in the life-test room with sufficient space to permit safe and convenient handling of lamps.

(e) **MEASUREMENT OF LIFE-TEST PERIODS.**—An important detail in conducting a life test is the accurate measurement of the time the lamps have burned. For this purpose an electric clock which measures time in hours from one to one thousand is used. This clock is connected in the master clock circuit of the Bureau and is short-circuited by a relay when the power is cut off. The log of any life test contains the clock time to the nearest 0.1 hour, corresponding to the time of placing the lamps on and removing them from the rack circuit. The time of burnouts during the night is either recorded by the watchman who visits the room every two hours, or the lamps are considered as having burned until 9 o'clock the following morning.

2. RECORDS TAKEN DURING LIFE TEST

Summarizing the records which are taken during life test, as described above, it will be found that the following have been mentioned:

(a) Test voltage; initial candlepower and initial wpc at test voltage.

(b) Candlepower and watts at certain periods during test life. For carbon and metallized filament lamps the specifications require measurement after approximately 50 hours of burning and "at least every hundred hours thereafter" throughout useful life. Five measurements, the first approximately one-twentieth of the test life period, after the initial are specified for tungsten lamps.

(c) Recording voltmeter records of main life test voltage.

(d) Test log showing clock reading from which test life periods are computed.

In addition to the above there are, of course, required such other records as will permit orderly clerical procedure. A card record system is used throughout, but the details, which have been worked out to take care of features in some cases peculiar to the Bureau tests only, would hardly be of general interest.

VII. SUMMARIES OF LIFE VALUES

After the completion of a sufficient number of test lamps to warrant quality comparisons, life values of lamps of the same type, size, and manufacture, and of a voltage range through which a given life value is specified, are averaged. A summary giving the date, type, size, manufacture, voltage range, number of lamps, corrected life and percentage of required life is prepared from these data, so that a manufacturer may, at his request, refer to the summary for information regarding the quality of his lamps and those of other manufacturers supplying lamps under the annual contract. In case lamps are rejected as the result of life test the manufacturer and purchaser are promptly notified, each being given the life value on which rejection is based.

Additions of other lamps are made to this summary from time to time, so that average quality values to the corresponding date are indicated; except that in case of a drop in quality of certain

items so decidedly below the required life that rejection of the defective lamps is necessary, the figures for accepted and rejected lamps are kept separate until the end of the tests, when the average life of accepted and rejected lamps combined is reported as a final value.

VII. SUMMARY

The method employed by the Bureau of Standards in the inspection and life testing of incandescent lamps for the Federal Government is outlined and a description of the power plant, the life racks, and the photometer is given. Particular attention is directed to the special equipment of the photometer. This includes a watts-per-candle computer and a recording device by which observed values of candlepower, watts, watts per candle, and actual life are recorded on a separate card for each lamp. These records are made in such a way that life at forced efficiency is corrected to life at normal without computation or reference to tables of factors. The procedure in actual measurement and testing is described with considerable detail.

WASHINGTON, July 31, 1915.