THE LIFE-TESTING OF SMALL THERMIONIC VALVES.*

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SUMMARY.

The paper discusses the basis of a life specification for thermionic valves, similar to those in force for electric lamps, and indicates the assistance which a life-test equipment and data afford in preparing such specifications. The general characteristics of thermionic valves are then described, in relation to the problems involved in designing such an installation. Solutions of these problems are then discussed more fully, and a large installation for testing the life of valves is described. Typical examples of the results obtained are given.

(1) INTRODUCTION.

This paper is a fulfilment of a forecast in a previous paper,† that methods adopted in the life-testing of valves would subsequently be described. The present object is, therefore, to describe in some detail the valve-life testing organization with which the authors are associated.‡

Certain advantages which are given by a life-test organization, such as the ability to control the production quality and to acquire knowledge of valve behaviour after many hundreds of hours' running, will be clear and need not be emphasized. In the same way, the assistance which a life-test installation affords in the design of new valve types will hardly need elaboration, particularly as the electric lamp industry has received material assistance in the past from similar installations. But the problem of running life-tests on thermionic valves is more complicated than the equivalent problem for lamps, due partly to the low operating voltages, and partly to the greater number of electrodes which are an essential feature of their construction. But despite dissimilarities from the case of the electric lamp, there is much that has been accomplished in the life-testing of lamps which can, with advantage, be applied to the testing of valves.

The valve industry will probably play as extensive a part in the present civilization, and one probably as valuable, as that played by the lamp industry. The time has already come when progress in development should be regulated by wise standards of performance fixed after a careful consideration of accumulated experimental data. This function has been performed for the lamp industry by the British Engineering Standards Association. At present valve types are multiplied almost at random, conforming to no universal standards of performance or manufacture, and the result is that, in this country alone, a bewildering number of types exists. The net result is of problematically small technical advantage to the user, and entails a sacrifice of the efficiency of manufacture, and uniformity of product, obtainable by standardization. It would seem inevitable that a British Standard Specification for valves should be considered, in the not far distant future, corresponding to the lamp specifications. Such specification would be most valuable if based on data which have accumulated during the life-testing of valves under carefully controlled conditions. It is hoped, therefore, that the present paper may stimulate interest in the preparation of such a specification, and also indicate methods by which reliable data may be obtained.

It should be made clear that, at present, only receiving types of valve are regularly life-tested in comparatively large numbers by the plant described in this paper, and any future extensions to cover the life-testing of the larger transmitting types are not discussed here.

In addition to the testing of valves with special experimental filaments, the life-test equipment has been used for tests on valves with bright tungsten filaments, with dull-emitting thoriated filaments, and with what are commonly known as coated, or "oxide" coated, filaments. The examples and remarks on methods of test given in the paper refer, however, only to the two former classes, as the considerable variations in total emission common to all "coated" filaments during life necessitate some alterations in the methods of checking the valve performance.

(2) GENERAL CONSIDERATIONS AFFECTING LIFE-TESTING OF VALVES.

The quantities which are of sufficient importance in receiving valves to warrant measurement during life are :—

(*a*) The filament current at rated voltage.
(*b*) The degree of vacuum.
(*c*) The total emission * from the filament at rated filament voltage.
(*d*) The voltage amplification factor.
(*e*) The internal impedance, as it is generally termed. By this is meant the ratio $\delta E/\delta I$, where $E =$ the anode voltage referred to the negative end of the filament, and $I =$ the anode current under specified conditions.

These are the factors which determine the performance of the valve when in use. In general, the

* Reprinted from *Journal I.E.E.*, 1926, vol. 64, p. 967.

† "Thermionic Valves with Dull-Emitting Filaments," *Journal I.E.E.*, 1924, vol. 62, p. 689.

‡ This installation is established at the Research Laboratories at Wembley for testing the product of the M.O. Valve Co. Our acknowledgements are due to the Directors of the M.O. Valve Co.

* Or some other measurement which is very sensitive to changes in the total emission (see page 190).

life will be satisfactory so long as (*a*), (*b*) and (*c*) remain close to their specified values, since, in this case, (*d*) and (*e*) rarely alter. It is clear that the investigation of life performance will be sound, only if such accuracy and constancy is maintained in the test conditions throughout life that failures under heading (*a*), (*b*) or (*c*) are due solely to conditions within the valves themselves.

(*a*) *Filament current.*—Measurements of filament current at rated voltage provide a check on two important factors :—

(i) The manufacturing accuracy of the filament dimensions (length and diameter).
(ii) The rate of evaporation, during the life-test, of the filament material. This applies mainly to bright tungsten filaments, and also to a smaller extent to oxide-coated filaments.

With regard to (i), it is pointed out, later on, that it is advisable to obtain a more reliable check on the accuracy of manufacture by carrying out "rating tests" on much larger batches of valves, which are returned to stock and not subjected to life-tests.

It should be borne in mind that the life of the valve filament is very seriously affected by a small change of filament voltage (and therefore temperature) during the life-test. In the case of valves of the bright-emitter class, early failure will follow upon an increase of filament voltage, by actual burn-out of the filament, consequent upon rapid evaporation of the metal.

With dull-emitter valves the emission may cease early, due to the more rapid evaporation of thorium at the higher temperature, if the filament voltage is above its maximum rated value.

Clearly, therefore, constancy of filament heating supply is a vital factor in the life performance of valves, and it is important that the life-test conditions should be maintained constant during the whole life of the valves, so that any change of filament emission or filament resistance which may occur shall not be due to the test conditions. Only in such circumstances can the test-results be taken as reliable and comparable one with another. From life-tests on vacuum-type incandescent lamps it is known that a law for bright tungsten filaments may be approximately stated in the following form :—

$$L = A\left(\frac{1}{V^{15\cdot5}}\right)$$

where L = filament life in hours ;
V = voltage across the filament ; and
A = a constant.

This may be taken as applying reasonably closely to the case of the bright-emitter valve filament, so much so as to give a result of the correct order.

Thus for a given filament at two different voltages V_1 and V_2

$$\frac{L_1}{L_2} = \left[\frac{V_2}{V_1}\right]^{15\cdot5}$$

From this approximate relationship it is seen that a 1 per cent change of voltage, in the region of the normal voltage, will produce, in bright tungsten filaments, a change in life performance of the order of 16 per cent.

The case of the dull-emitter valve is different from that of the bright emitter in that the former is not, except by accident, liable to failure through burn-out of its filament, but rather through decrease in its dull-emitting properties alone. A similar law to that for bright tungsten filaments applies to dull-emitter (thoriated) filaments, and although the exponent of V has not yet been quite so accurately determined, its value is of the same order as for tungsten. Small changes in voltage, therefore, affect valve life profoundly.

Of the other factors which are measured during the life of a valve, that falling under (*b*)—the degree of vacuum—is next in order of importance.

(*b*) *Degree of vacuum.*—The modern valve is manufactured with a residual gas pressure not exceeding 10^{-4} mm of mercury, and any increase in this pressure is liable to affect adversely the valve life, particularly of dull-emitter types.

Assuming that the exhaust has been satisfactory in manufacture, the final degree of vacuum will be generally reached, by the aid of the magnesium "getter," in conjunction with the well-known electrical clean-up effect, within the first 100 hours of life, and the pressure will generally remain thereafter of the order of 10^{-6} mm. The only cause which may increase this pressure is the liberation of occluded gas from the electrodes or from the bulb, and such an occurrence will be due to some faulty detail in the manufacturing procedure, or to an accidentally applied overload causing overheating of the electrodes. In receiving valves the permissible range of anode voltage is much wider than that of filament voltage, since the power dissipated at the anode is so small that even proportionately large variations in its value make little difference to the temperature of the anode or of the bulb.

While discussing the degree of vacuum from the point of view of life-test, it may be advantageous to amplify the data previously published by us on the subject.* In the earlier days of dull-emitter valve manufacture, a gas pressure not exceeding 10^{-5} mm was considered to be imperative if the duration of the thorium emission was to be satisfactory. But pressures as high as 10^{-2} mm were permissible, provided that the residual gas was solely hydrogen, though the more rigorous limit of 10^{-5} mm was retained because it could not be guaranteed that only hydrogen would be present. The use of magnesium as an aid to exhaust, and further manufacturing experience, have since modified that limit. The action of the magnesium is to clean up the gases which militate against thorium emission, and to leave behind chiefly hydrogen, which alone is harmless. Thus it may now be stated that, with magnesium "getter," an approximate upper limit of 10^{-4} mm is entirely satisfactory. The usual method of arriving at the approximate gas pressure is to measure the reverse grid current due to ionization. There is then an empirical relation of the form

$$\frac{i}{I} = Kp$$

* Loc. cit.

where i and I = grid and anode current respectively, p = gas pressure in mm of mercury, and K = a constant depending upon the nature of the residual gas, the anode and grid voltages, and the geometry of the electrodes.

For the D.E.R. type valve, with an anode potential of 50 volts and a grid potential of − 2 volts, and with hydrogen as the main residual gas, $K = 2$ approximately. For a pressure of 10^{-4} mm, and taking $I = 0\cdot5$ mA, we may solve for i, obtaining the value $0\cdot1\ \mu$A. This is therefore the limit of reverse grid current permitted on this type of valve, and vacuum tests are carried out, on those lines, enabling rapid determinations to be made with sufficient accuracy.

(*c*) *Total electron emission.*—A brief consideration of the relations between filament temperature and (*a*) voltage on the one hand and (*b*) emission on the other, will serve to show that the value of the emission changes very rapidly with voltage. From Richardson's equation $i = AT^{\frac{1}{2}}e^{-b/T}$ it is apparent that the emission is practically a logarithmic function of the temperature; it is also known that for a long tungsten filament at about 2 200° K. the voltage is approximately proportional to T^3. One would expect, therefore, that with changing filament temperature the emission will change much more rapidly than the voltage. Measurements on actual valve filaments show that a 1 per cent increase in voltage increases the emission by about 10 per cent for bright tungsten and by about 6 per cent for dull-emitting thoriated tungsten.

This point is important mainly in the measurement of valve characteristics during life test. The instruments employed must be of high accuracy, and the operator accustomed to taking close readings, if results obtained from successive valves are to be reliably comparable. Instruments which only just fall inside the British Standard Specification for sub-standard instruments are hardly good enough. In measuring the total emission it is usual to connect the anode and grid in parallel, and to measure the combined current at rated filament voltage and with a suitable anode-grid potential. The potential employed may be about 50 volts in the case of most receiving-valve types.

(*d*) *The voltage amplification factor.*—This is a constant for any one valve within reasonably wide limits on either side of the normal operating region, as it is dependent upon the geometry of the electrodes. The following empirical equation, due to H. J. Van der Bijl,* gives very good results and illustrates well the factors upon which this characteristic mainly depends :—

$$m = Cprn^2 + 1$$

where m = voltage amplification factor,
p = distance between plate and grid,
r = radius of grid wires,
n = number of grid wires per unit length,
C = a constant having the value 80 for the parallel-plane type of electrodes.

The accuracy of manufacture, therefore, determines the constancy of this characteristic between various valves of a type, but care has to be exercised in measuring it. By definition $m = \delta E/\delta e$, where δE = that change of anode voltage which would be equivalent in its effect on the plate current to a change δe in grid voltage.

It is usual, in order to facilitate the testing of large numbers of valves, to arrive at this ratio by taking two other ratios and dividing, thus :—

$$m = \left[\frac{\delta I}{\delta e} \div \frac{\delta I}{\delta E}\right] = \frac{\delta E}{\delta e}$$

where δI is the change in anode current occasioned by changes δe and δE in the grid and anode voltages respectively. Unless great care is exercised in making the measurements, the experimental errors may become comparable with those due to variations in manufacture.

The alternative method of plotting anode and grid voltages for a constant anode current is no doubt more accurate, but requires considerably more time. The ratio $\delta I/\delta E$ has to be measured, in any case, in order to determine the anode resistance, so that only $\delta I/\delta e$ is required, which merely involves two readings.

(*e*) *Internal impedance.*—The final characteristic to be considered is that known as the internal " impedance " or " internal resistance " of the valve. It should be noted that, in general, the term " impedance " is not strictly accurate, since it should include the inter-electrode capacity reactance, and the term " anode resistance " is perhaps preferable. In ordinary test procedure this inter-electrode capacity is neglected. Denoting this characteristic by R it may be defined as the ratio $\delta E/\delta I$. In routine work it is convenient to record δI for a constant change δE. The value of R obtained is less subject to serious error than was the case in measuring the voltage amplification factor m, but it should be noted that R is a function not only of the geometry of the valve, but also of the emission, and care must be taken to see that the filament voltage, which determines the latter, is correct. This characteristic is, therefore, one which may be adversely affected during the valve's life by incorrect life-test conditions, mainly incorrect filament voltage, leading to an impaired emission.

Rating Tests.

It will be seen that the procedure of life-test amounts simply to a series of tests of the rated characteristics of the valves during their life. As in the case of lamps, the number of valves manufactured is so great compared with the number which can possibly be tested, that it is usual to take rating tests on comparatively large batches of valves selected at random from stock, in addition to the limited number subjected to life-test. These large batches are then returned to stock. This procedure has been carried out in the case of incandescent-lamp testing in the past, and is now extended to valve testing. It is very valuable in enabling a closer check to be kept upon the general conformance of the product with its advertised rating, even though it gives no information about subsequent adherence to that rating. It may be of general interest to give a more detailed account of these tests, together with actual examples of the sort of spread of characteristics which is obtained in large-scale manufacture. The

* H. J. Van der Bijl: "The Thermionic Vacuum Tube," 1st edn., ch. 7, pp. 231 and 232.

batches of valves are obtained by haphazard selection of boxes of 50 from the despatch department of the manufacturer. The marked boxes are then sent to the laboratory, where the rating tests are carried out, without any preliminary treatment. To take one type, as an example of the routine, the measurements carried out are as follows (the rated filament voltage being 5 to 6) :—

(a) Filament current is measured at $E_f = 5 \cdot 4$, where E_f is the filament voltage.
(b) Total emission (I_e) is measured at $E_f = 5 \cdot 4$, and $E = e = 50$ volts, where E is the anode voltage and e the grid voltage.
(c) The quality of vacuum is determined by measuring the reverse grid current (backlash) at $E_f = 5 \cdot 4$, $E = 120$, and $e = -2$.
(d) Grid current (i.e. electron current) is measured at $E_f = 5 \cdot 4$, $e = +5 \cdot 4$, and $E = 120$.
(e) $\delta I/\delta e$ is determined by measuring I at $E_f = 5 \cdot 4$, $E = 100$, and $e = -4$ and 0.
(f) $\delta I/\delta E$ is determined by measuring I at $E_f = 5 \cdot 4$, $e = -2$, and $E = 100$ and 120.
(g) m, the voltage amplification factor, is obtained by dividing (e) by (f).
(h) R_a, the anode resistance, is the reciprocal of (f).

Target diagrams of which Fig. 1 (a) and 1 (b) are examples for two types of valves are then obtained by plotting m against R. In Figs. 1 (a) and 1 (b) are outlined also the limits for $\pm$ 20 per cent variation in m and R_a. Other types of valves are treated in a similar way, some or all of the voltages being different, depending upon the purposes for which the valve is most generally used. The main principle in every case is to make the measurements in the usual operating regions of the characteristics.

With most dull-emitter types, upper and lower limits are given for the voltage rating of the filament, which is designed to give :—

(a) Sufficient emission for satisfactory operation at the lower limit.
(b) A reasonable life at the upper limit.

This tradition in design is, of course, based upon the behaviour of the lead accumulator during discharge. The net result is that, provided the appropriate number of lead cells is employed, it is almost impossible for the user to shorten the valve life seriously by over-running the filament. This 10 per cent voltage range is of course only possible at the sacrifice of a certain amount of overall efficiency, and it is possible that the range may suffer reduction in the future, for the sake of greater filament efficiency.

When carrying out the rating tests, it is our practice to do so at the lower limit of the filament voltage range. Even then, with large amplifier valves, the total electron emission from the filament may be so great that, in measuring it, there may be dissipated as heat in the grid and anode an amount of power which is much greater than these electrodes have to withstand in normal operation. Indeed, with many types of oxide-coated-cathode valves it is useless to attempt a measurement of large amounts of total emission, because over-heating of electrodes causes liberation of gas which, when ionized, adds to the space current, and, by bombardment, causes additional heating of the cathode coating, thereby destroying any value which the emission measurement might have.

Considerations such as these have so far prevented us from rating valve filaments according to their electron emission, which quantity is, of course, strictly analogous in filament design to the candle-power rating of lamp filaments.

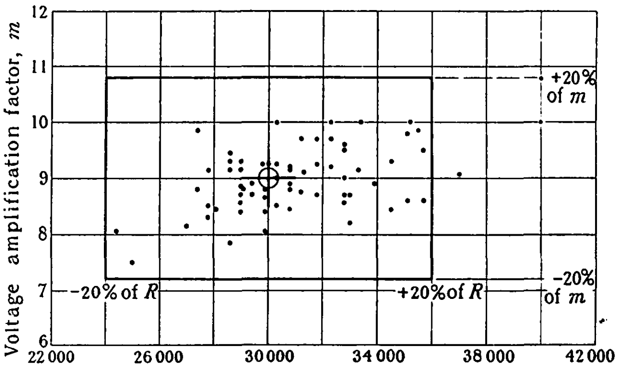

FIG. 1 (a).

In selecting lamps for life-test it is the practice to subject a large number to a candle-power rating test, and, from this large number, to select for life-test a comparatively small number, the candle-power ratings of which lie within the narrow central zone of the total spread shown by the large number. The average life of this small number which is life-tested, is, of course, much more truly representative of the average life of the factory product than would be the average life of a

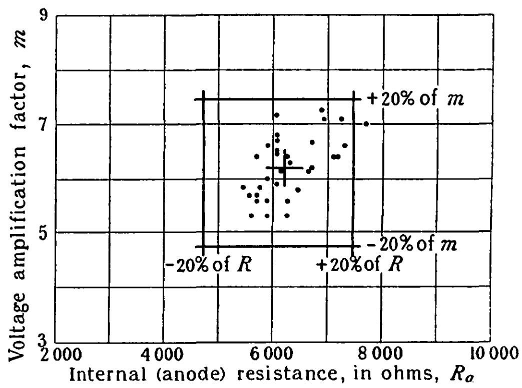

FIG. 1 (b).

similar number of lamps selected at random, without the aid of a rating test.

Whenever the time comes to draw up a Standard Specification for valve life, the question of the method of selection of a batch for test will no doubt be of considerable importance, and it is unfortunate that the method of choosing for test a few valves, the filaments of which are operated at a temperature which is a mean for a larger number of filaments, is not directly applicable.

There is, of course, the oscillograph method of measuring total emission, but this would probably prove to be too elaborate for incorporation in any proposed specification. Another possible method of fixing a total emission rating might be made dependent on emission measurements at a filament voltage considerably lower than the rated value; but the method would require an accurate knowledge of the voltage/emission relationship for all types of cathode, and might, therefore, be cumbersome and difficult to establish. In specifying the method of selection of valves for life-test there appears, then, to be no likely alternative to the choice of the completely haphazard method.

To return to the rating specifications themselves, altogether apart from life-test problems, there is with

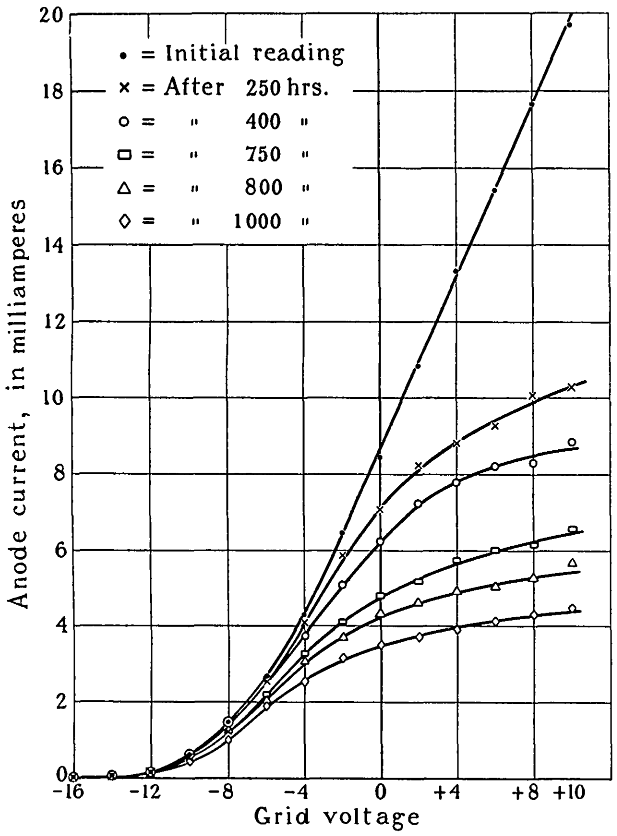

FIG. 1 (c).

them no real necessity to specify values of total emission. Total-emission measurements in receiving valves are, after all, principally made in order to ensure that there is amply sufficient to satisfy the anode characteristic, or, in other words, to ensure that this characteristic does not begin to bend over in the operating region. An alternative method of ensuring this would be to specify, for example, that

$$\left[\frac{\delta I}{\delta e}\right]_{e=+4}^{e=0} \not< \left[\frac{\delta I}{\delta e}\right]_{e=0}^{e=-4}$$

with rated filament voltage, and at the upper anode voltage rating. For purposes of illustration, an example of what happens to the anode characteristic as a result of rapidly decreasing emission is given in Fig. 1 (*c*).

SUGGESTIONS FOR A STANDARD LIFE SPECIFICATION.

The chief causes which terminate the life of a valve are :—

(*a*) filament failure,
(*b*) electrodes (or leads thereto) making contact with each other,
(*c*) loss of vacuum,
(*d*) loss of emission, with resulting deterioration in characteristics.

(*a*), (*b*) and (*c*) are all either self-determined or easily defined, so that (*d*) is the only factor for which it would be at all difficult to specity standards of life performance. In view of the difficulties in emission measurement, already discussed, a specification of emission life would probably be much more satisfactorily based upon measurements of anode characteristic. There are many possible modifications of this measurement which could be made at intervals during the life-test, such as :—

(*a*) the plotting of a short section of the complete curve,
(*b*) an internal resistance [$\delta E/\delta I$] measurement,
(*c*) some single point, which is very sensitive to emission change, such as the anode current (I_0) at the maximum rated anode voltage, with zero or slightly positive grid voltage, and rated filament voltage.

The life specification could then include a certain maximum permissible decrease (20 per cent or so) in I_0, or an increase in R_a of the same order, analogous to the permissible decrease in candle-power embodied in lamp specifications.

Some such specification of stability for I_0 or R_a would, if fulfilled, quite well ensure stability of emission, and, after all, the user of a receiving valve, whilst not directly interested in the stability of I_e, is keenly concerned with the stability of R_a.

(3) CONSIDERATIONS INVOLVED IN THE DESIGN OF A LIFE-TESTING INSTALLATION.

These points will be discussed under the following heads :—

(*a*) The types of supply for filament, grid and anode, and their permissible degree of fluctuation and methods of regulation.
(*b*) Details of the installation at Wembley.
(*c*) The accommodation required in order that representative numbers of valves of all types manufactured may be tested.
(*d*) The installation for measuring valve characteristics.
(*e*) The system of filing and plotting the results so that the maximum information may be obtained from the tests.

(*a*) TYPES OF SUPPLY.

Filament-heating supply.—The principal difficulty in designing a valve life-test installation lies in arranging a suitable supply for the filaments. It is always difficult to obtain voltages constant to 1 per cent, having regard to such changes of load as occur due to the failure of a filament in one valve of a batch, or to switching in or out of valves. The difficulty is enhanced with the wide range of voltages which must be provided.

A simple calculation shows that it is quite impracticable to adjust the voltages of a batch by feeding from busbars through a common rheostat. Thus, the number of valves all burning at, say, 6 volts off a 12-volt supply through a common rheostat must exceed 200 if failure of two of them, which may occur when the installation is unattended, is not to alter the voltage on the remainder by 1 per cent, whilst removal of valves for test would necessitate constant adjustment of the voltage.

One obvious solution which presents itself is to use a separate rheostat for each valve, coupled with a supply transformer (if such be installed) of large capacity. For a small installation of 100 or so valves this method might be adopted. It suffers, however, from serious drawbacks:—

(*a*) Provision must be made for testing the voltage on each valve separately. Apart from the necessary switching gear, sockets, or tapping switches, this involves unnecessary labour when a number of valves are being tested on the same voltage, as is often the case.

(*b*) Trouble is likely to arise due to varying contact resistances on the rheostats, and to voltage-drop due to current taken by the low-reading a.c. voltmeter.

(*c*) Rheostats of sufficient range and current capacity take a good deal of space.

Nevertheless, for a small installation, particularly if allowance must be made for many different voltages, this solution is probably the best. It can be used with either a d.c. or a.c. supply, the latter having the great advantage that step-down transformers can be used with tappings to give low voltages, so that the whole installation can be fed from the customary high voltages. Whatever supply is used, however, it is clear that special steps must be taken to maintain it constant to within 1 per cent, a constancy which is, of course, not attained with any ordinary commercial supply.

The alternative method, which has been adopted with satisfactory results in the installation to be described, is the supply of small batches of valves from 415-volt busbars, kept constant within $\pm \frac{1}{2}$ per cent by an automatic voltage regulator, through induction regulators and step-down transformers. Such an installation is capable of expansion to cover many hundreds of valves, and requires no attention beyond the daily routine check of voltage on each batch of valves. With a suitably designed transformer and induction regulator the effect of failure of some of the valves is negligible.

The induction regulators, being on the supply side, may be of standard type. The number of valves to be fed by one transformer, and the number of transformers controlled by one regulator, depend on the size of batches and degree of flexibility required. Details of a particular installation are given below.

In deciding on such an installation, it was, of course, necessary to be satisfied that the results obtained by testing with alternating current would give the desired information, having in mind the fact that valves are normally burnt on direct current. That this is very probably so has been shown by a large number of tests carried out on batches of similar valves by both methods. We also have evidence from the life-testing of lamps, where it has been shown that no essential difference exists. Care should be taken, however, in the case of valves normally requiring a very large emission current compared with their filament current, such as some types of transmitting valve. In such a case, however, the whole method of test would be different and the installation described is not intended to deal with them. In any case, it is to be remembered that what is chiefly required is a comparison between different types of valve, or between different batches of the same type, rather than an absolute figure to a high degree of accuracy.

Although, as has been stated above, our object in conducting life-tests has so far been directed towards obtaining reliable figures for comparison, rather than data directly applicable to the conditions under which the valves are used by the public, it must be admitted that such data may one day be required. We do not anticipate that any great difference will be found between valve life on a.c. filament-heating, as against life on d.c. heating, but we cannot make a definite statement until further special and extensive d.c. tests have been run. General information, such as is forthcoming from large users of valves burnt on direct current, points to the correctness of our opinion, and it should be added that the practice of burning all valves on life-test at the upper limit of their filament voltage-rating will be undoubtedly more severe on them than are the d.c. operating voltages generally used.

The greatest differences between d.c. and a.c. testing will, of course, be obtained in valves in which the mean anode current bears the greatest ratio to the filament current. A very approximate estimate for a valve the thoriated filament of which requires a current of 120 mA at 6 volts, and which in normal use gives a mean anode current of 5 mA, indicates that under d.c. conditions, as a result of progressive loss of emission at the hotter negative end, the useful length of filament will be about 90 per cent of its initial value after completing 70 per cent of the life which is obtained when similar valves are tested at the same filament voltage, but with alternating current. In order to ensure, with this particular type of valve, that during d.c. operation no part of the filament shall be hotter than the hottest central portion would be under the 6 volts (a.c.) conditions, then the d.c. voltage would require to be as low as about 5·8 volts.

These figures deliberately overestimate the magnitude of the effect, for they neglect the appreciable amount of anode current emitted by the end of the filament which is within reach of the cooling action of the supporting wire, and they are also based upon conservative figures for the relation between life and temperature.

Anode and grid supplies.—These are still to be considered. In the case of the former, the use of direct current is desirable if the normal operation of the valve is to be imitated, and, since, unlike the filament voltage, there is no very close limit within which the anode voltage must remain, it is both convenient and satisfactory to obtain the anode voltage from a potential-divider. It is also satisfactory in practice to employ only one potential-divider, provided with four sliders, for four sections of valves.

The provision of the anode current from a separate d.c. generator, suitably driven and equipped, is preferable to the use of storage batteries, on account of the size of accumulator which would be entailed.

Finally, there remains the question of supply to the grids of valves under test. It is clearly important, if practical conditions are to be imitated, that valves of the low-frequency amplifier type should be life-tested with a definite grid bias. This involves the use of direct current, but the problem differs in several particulars from that of the anode supply. In the first place, the question is purely one of applying a potential to the grids, the current being inappreciable. The highest value of potential required is comparatively low and, in the case of smaller valves, not more than 1 or 2 volts. A supply is needed, therefore, which will remain constant in potential over long periods of time, and which is not required to provide power. It would clearly be uneconomical to employ rotating machinery for the production of such a supply. The use of dry cells is unsatisfactory on account of deterioration, whilst the lead-plate accumulator battery is not suitable where long periods of inaction are necessary, as in this case. A satisfactory supply is to be found in the use of nickel-iron storage cells, which offer the following advantages :—

(*a*) High permissible charging rate.
(*b*) Low voltage per cell (1·25 volts normal), thus allowing suitable voltages to be obtained without the use of potential-dividers.
(*c*) Low self-discharge.

These cells can be allowed to stand for much longer periods when in a charged condition, without recharge, than can the lead accumulator, and, moreover, a slow trickling discharge does not appear to cause deterioration to the same extent as in the more usual type of battery.

Thus, provision for the grid supply is satisfactorily made by a battery of these small nickel-iron cells, and this may feed the entire installation, each section of valves having a selector switch by which any one of a series of predetermined voltages may be tapped from the battery.

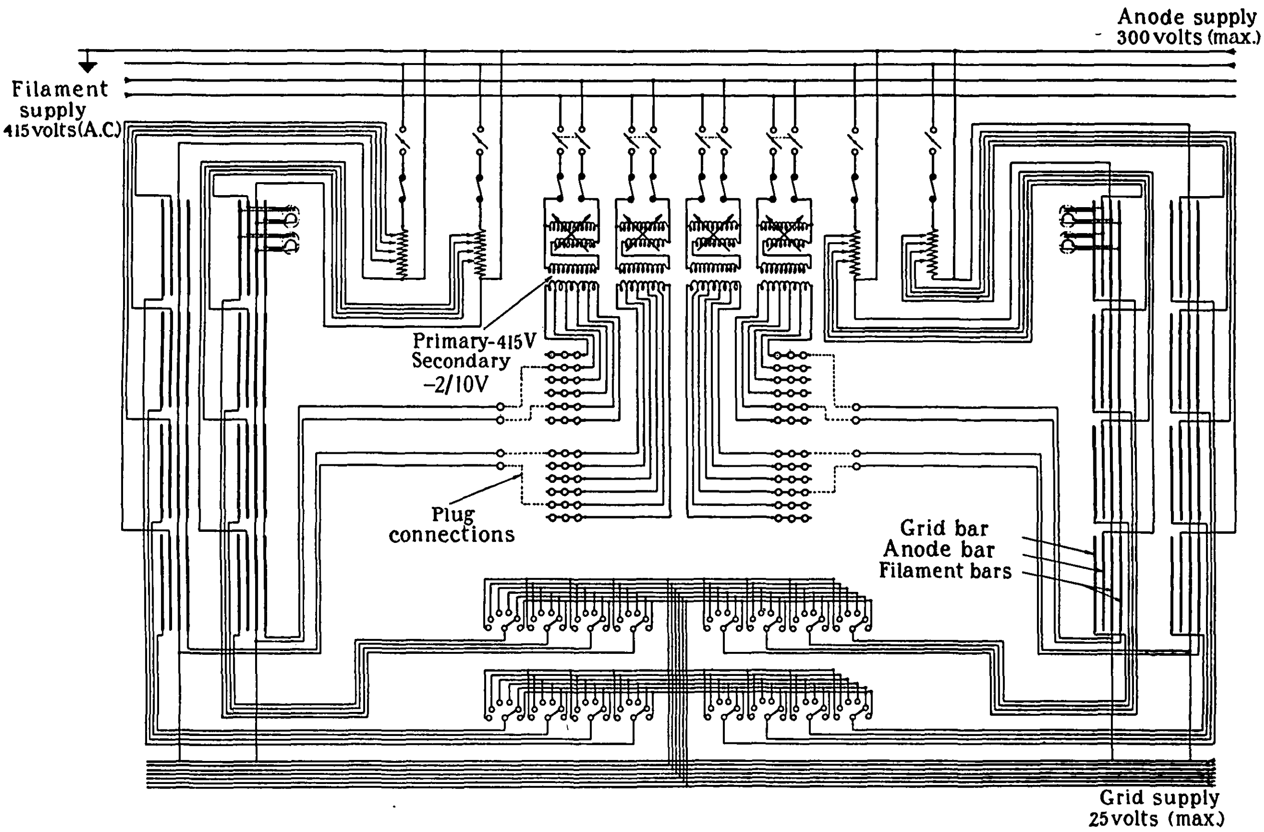

Fig. 2.

(*b*) Details of the Installation at Wembley.

For filament and anode-current supply a special motor-generator set is installed. This set, which was designed for lamp life-test work, consists of a 90-h.p. 415-volt three-phase motor directly coupled to a 50-kW 415-volt single-phase alternator, and, on the same shaft, two 2·5 kW 150-volt d.c. generators, the latter electrically connected to provide a 150–0–150-volt three-wire supply.

Fig. 2 shows a complete diagram of connections, and Fig. 3 the actual arrangement.

The 415-volt alternator is regulated by means of an automatic voltage regulator, which maintains the voltage constant to within $\pm \frac{1}{2}$ per cent. The valve anodes are fed from the 150–0–150 d.c. system. The framework holding the racks and local control-gear is of angle iron, mounted parallel to, and about 3 ft. from, the wall, the racks themselves being fixed to, and projecting from, this framework, thus forming alcoves, each of which is about 3 ft. wide. The control panels for each alcove are supported on the angle iron between the racks, and the transformers and other heavy gear are installed behind the panels.

Since all the racks are similar, it is only necessary to describe one alcove (a typical view of which is shown in Fig. 3). The whole of an alcove, with its attendant gear, only occupies a floor-space of approximately 4 ft. × 3 ft. Each consists of half of two projecting racks, the control panels being between them, and the heavy gear mounted behind.

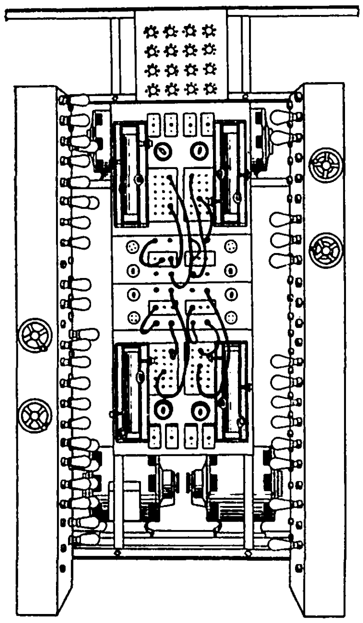

FIG. 3.

Each alcove has a capacity of 96 valves, arranged in four vertical sections of 24, two sections being mounted on each side of the alcove. Separate filament control is arranged for each section, which, in addition, is divided into four sets of six valves with separate anode and grid control. In other words, each alcove of 96 valves has accommodation for 16 sets of six valves with variable grid and anode voltages, these sets being arranged in groups of four, each bank of 24 valves so formed having separate filament-voltage adjustment. A reference to the diagram of connections will make this arrangement clear.

The control panels are of slate, and have mounted upon them the circuit switches and fuses for the filament and anode feeds, the anode potential-dividers, the filament supply socket bars, and the filament rack sockets. The actual valve-holder racks are of wood, with bakelite fronts, on the face of which are mounted the valve-holders, the supply busbars being carried at the back. To ensure good contact between the valve pins and the sockets, the latter are made self-aligning, so that any slight difference in the centres of the pins is taken up by the sockets.

For the filaments, the 415-volt supply is brought to the primaries of $\frac{1}{2}$-kVA transformers, having tappings on the secondaries at 2, 3, 4, 7 and 10 volts. In the primary circuit of each transformer is connected an induction regulator, capable of boosting and bucking $33\frac{1}{3}$ per cent of the normal voltage, and the transformer secondary tappings are so arranged that this variation on the transformer primary will give a continuous range of voltage from 1·33 up to 13·5 volts on the secondary.

Each secondary tapping is taken to a socket bar mounted on the control panels, and further sockets are connected to the filament bars of the racks. There are thus no moving contacts in circuit with the filaments—a very important feature. When setting up valves, a plug connection is made by flexible leads between suitable socket bars and the filament sockets. The plug-and-socket joints are well-made tapers, and excellent electrical contact is ensured, provided that care is taken initially in fitting the tapers.

Too much stress cannot be laid upon this question of contact voltage-drop. In the system described here, any contact may be called upon to carry a normal full load of 50 amperes, and for this reason it is the best practice, in view of the low voltage, and the close regulation required, to solder cables to the transformer secondaries rather than to make bolted connections thereto. Extra-heavy cables should be employed, and, in the design of the transformers, the copper should be increased so that the iron losses predominate, in order that the voltage regulation may be improved.

The question of flexibility is very important. We have found that subdivision of the filament supplies, so that each batch of 24 valves is independent as regards filament voltage, is barely sufficient. The designer should aim at subdivision into independent batches of 12 valves, and should also arrange that a portion, at least, of each 12 is so equipped that a series rheostat could, in special cases, be readily introduced into each filament circuit. Such a system would allow the testing of small batches of valves at unusual voltages, without disorganizing the routine work or causing numerous other sockets on the same voltage to stand idle, and the auxiliary system of single rheostats would not give rise to regulation trouble in the event of valves burning out.

Returning to the description of the plant, the anode supply is solidly connected through a potential-divider of 1 400 ohms resistance to the anode bars.

For grid supply there is mounted above each alcove a panel containing 16 small 6-point selector switches, one switch for each set of 6 valves. The switch points are connected to tappings on the grid battery, the range covering 25 volts, and the switch arms are taken direct to the grid bars.

(c) AMOUNT AND NATURE OF ACCOMMODATION REQUIRED.

The amount of accommodation, in the case of the plant under discussion, has been based upon figures which have become recognized as standard in the life-testing of incandescent lamps. A compromise has to be effected between the testing of large numbers and the cost of such testing—both the initial cost of plant and the running costs. As with types of lamps in which the production is very large, running in some cases to hundreds of thousands per week, so with valves does the number tested have to be a very small percentage of the total production. In our case, the number of valves tested per week is of the order of 1 per 1 000 produced. Now it must be remembered that if, for example, 1 valve per week is taken, accommodation has to be provided for 6 such valves, since, on the basis of 1 000 hours' life-test, approximately 6 weeks are required to complete the test on each valve. Testing provision has therefore to be made for 6 times the number of valves collected from production per week.

installation under review, provision is made for experimental and modified valves equal to that for stock production valves, for the research work necessary in producing a successful new type of valve will involve the testing of many trial valves over periods of months.

These are the chief considerations which influence the accommodation required in a plant adequate for its purposes. In the installation discussed in this paper, a satisfactory compromise has been made by providing for approximately 600 valves to be burning at one time.

(*d*) The Installation for Measuring Valve Characteristics.

To deal with the characteristic testing of 600 life-test valves, at least two permanently equipped test-tables are needed. Direct current, with series-resistance

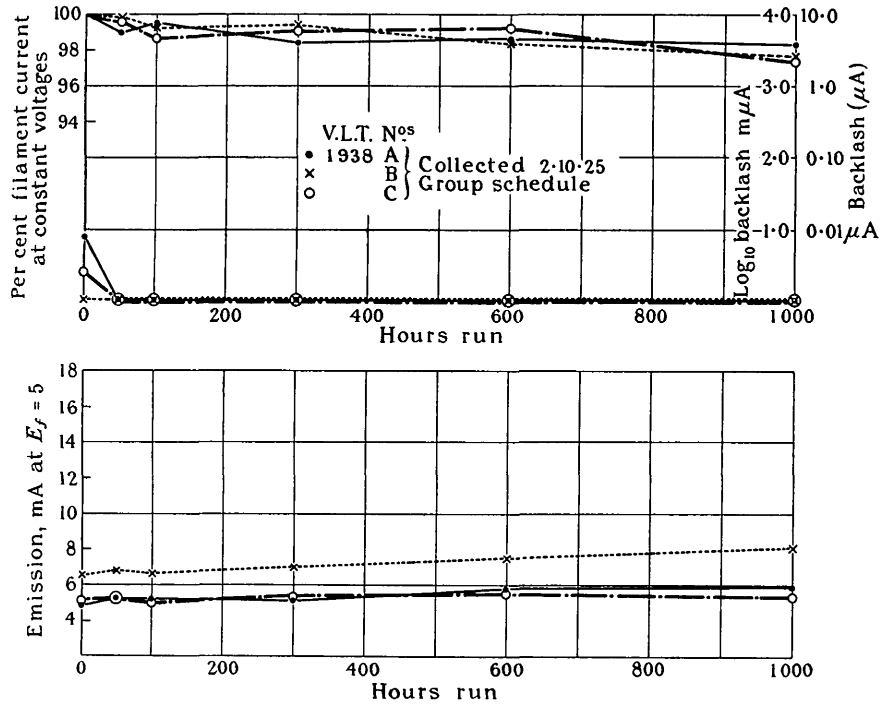

Fig. 4.

In the case of valves which are made only in comparatively small numbers, such as special types for short-wave work, or the larger types of power valves, the number tested will naturally have to be greater than 1 per 1 000 per week, as, in general, it is the best practice to collect valves for test at the shortest possible intervals, and certainly not less frequently than once per week. Where more than 1 valve per type per week is collected, the times of collection should be spaced evenly throughout the week. The significance of this factor is shown in the case of types produced in small numbers, for in such cases 1 valve per week should still be collected, and hence the collection figure may rise to 1 in 100 for certain types, or even higher, and every valve collected per week means that accommodation for 6 valves has to be provided. In the

control for the filament supply, and potential-divider control for anode and grid supplies, is satisfactory. High-grade multi-range instruments are required for measuring, and the calibration of filament voltmeters is necessary at frequent intervals. Reflecting galvanometers with variable shunts, and preferably sensitive to 1/1000th of a microampere, are necessary for rapid estimations of vacuum. The design of such tables should allow for the quick provision of abnormally large filament, anode, or grid voltages for special tests, or for insertion of extra resistance in any circuit. Provision should be made in the wiring to allow for testing of abnormal valve types (such, for example, as the 4-electrode type), by bringing leads out, in parallel with the usual valve-socket leads, to terminals situated, preferably, above the table-level. The latter device enables uncapped valves to be tested with the same rapidity as capped valves. All meters should be well illuminated and mounted close together, preferably inclined at an angle to the vertical in order to facilitate quick reading without parallax errors.

(e) THE SYSTEM OF CURVE-PLOTTING AND FILING OF RESULTS.

As this Section may perhaps be of less general interest than other matter in the paper, it is relegated to an Appendix, where full details are given.

(4) EXAMPLES OF THE OPERATION OF A LIFE-TESTING ORGANIZATION.

So far as the general results of life-tests are concerned, the behaviour of bright tungsten filament valves is closely comparable with that of tungsten vacuum lamps, on which data have been published. Furthermore, the behaviour of the thoriated dull-emitter during life has already been discussed by Thompson and Bartlett.* In these circumstances a brief reference to the main life characteristics of both types will suffice.

Fig. 4 shows a typical set of curves upon a good batch of three bright tungsten-filament valves. Considering the top curves, it will be noted that the filament current at constant voltage decreases during 1 000 hours' life by about 3 per cent of its original value. This is due to evaporation of tungsten, at the high operating temperature, resulting in decreasing filament diameter and increasing resistance. Eventually the combined action of filament tension and local overheating due to this cause results in failure through fracture. (The bright emitter generally fails in that manner.) The middle curves show that the vacuum, though sufficiently good initially, was much better after 50 hours of life had expired, and that it remained so until the valves were taken off test after 1 000 hours' running. The lower curves indicate a general rise of emission, at constant filament voltage, during life, indicating that the filament temperature increases gradually at points where evaporation of the metal has occurred, raising the total value of emission from the filament.

Fig. 5 shows typical results from good dull-emitter valves of uniform construction, run at the top limit of their designed voltage. The plotting of filament current is of little value with dull-emitting types, since the low temperature at which they run produces no observable thinning of the filament. It will be again noted that the vacuum became practically "dead hard" early in life, due to the electrical clean-up effect. The test-results shown were taken with a filament voltage of 5·4, but the life-test was run at 6·0 volts, which is the maximum rated voltage for the valve shown, and needlessly high for ordinary use. It is a good general principle in valve-life testing to run the actual test at the maximum rated filament voltage, and to take the. characteristic measurements at, or about, the lower rated filament voltage. Valves which are satisfactory under such test conditions would be satisfactory to the user. It will be seen that there is a slight decline of emission during life, but all the valves still had, after 1 000 hours, 50 per cent more emission than would be required for satisfactory operation.

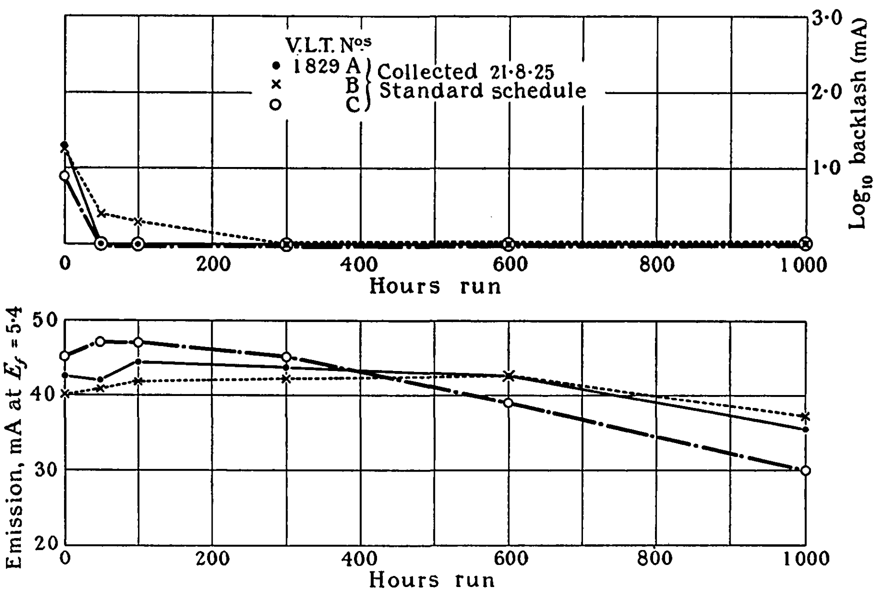

FIG. 5.

* Loc. cit.

APPENDIX.

THE SYSTEM OF CURVE PLOTTING AND FILING OF RESULTS.

It is impossible to lay down hard-and-fast rules, but certain general principles may be indicated.

First, a system should be initiated whereby every valve of the 600 which may be burning should be capable of rapid identification, and full particulars of its design data, etc., easily available. This involves a series of stock sheets such as that of which the top is illustrated in Fig. 6, giving the position and number of any valve, and preferably a series of small cards such as are illustrated by Fig. 8, the cards being held in a clip provided at each valve socket. By this combination of cards and sheets, it is assured that the valve concerned shall fulfilling the functions just described, ensures also, if the small rack card is continuously left in its clip until the valve either completes its allotted life period or fails, that the socket belonging to that valve must be regarded as occupied, even if the valve is removed for purposes of measurement. Confusion is thus avoided when several operators are at work, and one may be wishing to place valves on life-test while another has

Drawing number	Type	Date for 1 000 hours	600	300	100	50	Commencing date	Life test number	Index number	Res. assistant	Experiment number	Filament volts	Grid volts	Anode volts	Number of valves	Rack number	Remarks
2043		6/1	20/12	8/12	30/11/25	28/11/25	26/11/25	2078		S		5	0	50	3	17C	13/11/25 Group Schedule

FIG. 6.

VALVE LIFE TEST No. 2078

.... Valves. Filament Volts = 5 Grid Volts = 0 Anode Volts = 50

Remarks: 13/11/25 GROUP SCHEDULE

Date	Hours	Filament characteristic and rating		Vacuum		Grid, i	Valve characteristics. $E_f = 5$									
		$E_f = 5$ volts		$E = 150$ $e = 2$		$E = 50$	$E = 50$		$10^5 \times K_1$ mhos	$e = 0$		$10^5 \times K_2$ mhos	m	$10^{-3} \times R$ ohms		
		$\left.\begin{matrix}E\\e\end{matrix}\right\} = 0$	$\left.\begin{matrix}E\\e\end{matrix}\right\} = 50$	Total, i	Leak, i	$E_f = 5$ $e = 0$	$e = -1$	$e = +1$		$E = 40$	$E = 60$					
		I_f	I_e				I	I		I	I					
26 Nov.	A	0·720	5·92	−58	−1	6·9	1·01	1·57	28·0	0·95	1·52	2·85	9·83	35·1		
28 Nov.	50	0·716	8·41	−6	0											
30 Nov.	100	0·714	8·34	−3	−2											
18 Dec.	300	0·710	7·19	−1		7·8	0·95	1·49	27·0	0·91	1·58	3·35	8·06	29·9		
20 Dec.	600	0·70	8·01	−1												
28 Dec.	800	Filamen	t Failu	re												
26 Nov.	B	0·712	5·41	−112	−1	5·8	0·85	1·43	29·0	0·83	1·47	3·2	9·07	31·3		
28 Nov.	50	0·710	6·89	−10	0											
30 Nov.	100	0·702	7·67	−8	−2											
18 Dec.	300	0·702	7·21	−3	−3	5·8	0·82	1·39	28·5	0·79	1·48	3·45	8·27	29·0		
20 Dec.	600	0·70	7·60	−3	−3											
6 Jan.	1 000	0·670	7·91	0		6·1	0·75	1·26	25·5	0·73	1·29	2·8	9·12	35·7		

FIG. 7.

have its characteristic measurements taken at the correct periods during its life. To each batch of valves, of every type, a serial number is allotted, and, in that batch, the valves are able to be identified by carrying a distinctive letter. Thus, a batch of valves might, for example, have the serial number 2078, and a given valve of that batch might be 2078A. This classification numbering is etched on every valve, and is also marked on the small card (Fig. 8) clipped beside the valve during the whole of its life. This system, whilst entirely valves removed for the measurement of characteristics. This point is of greater practical importance than might appear at first sight.

Measurements are made upon the valves in general at 0, 50, 100, 300, 600 and 1 000 hours during life, though at more frequent intervals in certain cases. The results are recorded in such a way as—

(*a*) To illustrate, in a graphical manner, the behaviour of the valves and thus to enable the manufacturer to modify his methods of production where necessary, with the minimum of delay. To accomplish this, cards are prepared for each batch of valves (see Fig. 7), so designed that complete information is given of all the ordinary characteristics. In addition, two blank columns on the right-hand side of these cards enable measurements on additional properties, such as

VALVE LIFE TEST. No. 2078A

Exp. No.________

Type or Name

____

E_f 5·0

E 50

e 0

Remarks : Stock

FIG. 8.

detector action and degree of microphonic property of each valve, to be recorded if desired. The more important results entered are then plotted on tracing paper (see Fig. 11), and blue prints of these graphs are sent to the manufacturing sections producing the valves.

(*b*) To amass data which may be analysed from time to time, so providing statistics covering the whole range of the production schedule over periods of months, enabling valuable deductions to be made as to the effect

________ Factory. V.L.T. No. 2078

STOCK
VALVE LIFE TEST

Drg. No. V.L.T. 2043 F

5·0 Filt. }
0 Grid } Volts
50·0 Anode }

Res. Asst. }
Wks. Supt. } ________

Date 26/11/25

Life Test of 3 Valves

Manufactured 13/11/25

on Life Test 26/11/25

Remarks : Group Schedule

FIG. 9.

INTERIM REPORT ON VALVE LIFE TEST No. 2078A

Date 28/12/25 Failed at 800 Hours

Remarks : Filament Failure.

____

Number of Valves Burning 2/3

Valve retained by________

FIG. 10.

of small changes in design, and so forth. In Fig. 9 is reproduced a slip which is made out in triplicate, one copy for works' information and two for reference, as

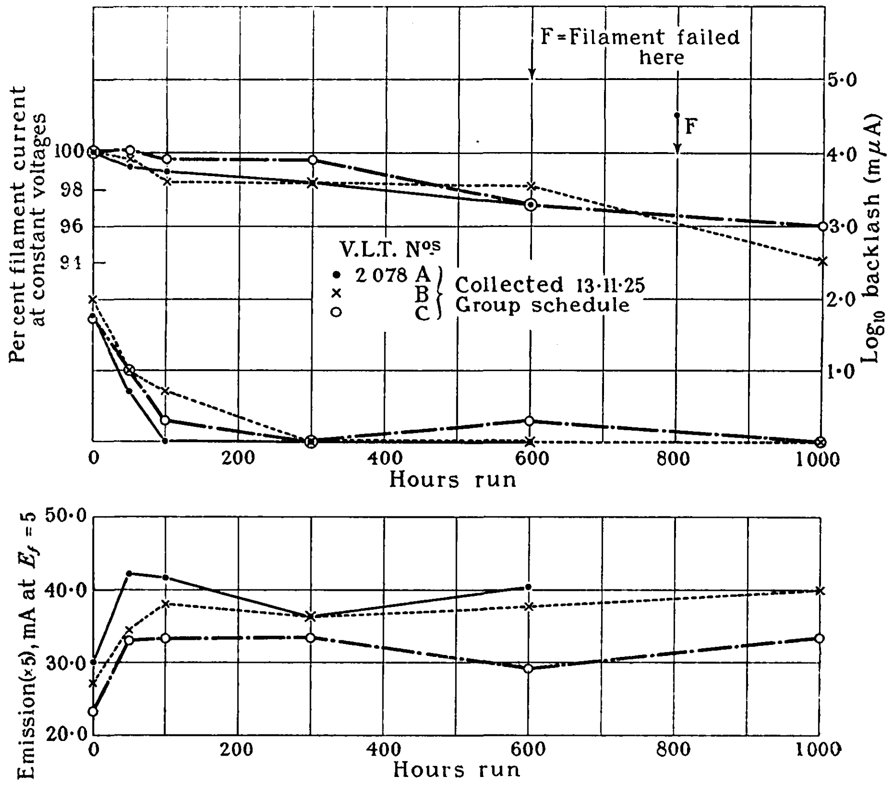

FIG. 11.

soon as a batch of valves is put on life test. An exactly similar procedure is adopted with the slip illustrated in Fig. 10, which is made out when any single valve of a batch fails on life-test.

To make the system in use at Wembley clear, the case of a batch of two valves of stock production will be considered, in which one valve is entirely satisfactory, and one fails after some hundreds of hours' running.

These valves, in common with all stock valves tested, are selected at random by a representative of the testing laboratory, and are chosen during the last stage of manufacture. On arrival at the Laboratories they are checked against the collection schedule for that type of valve, are then each given a distinctive number, which is etched on the bulb, and their full details entered in the valve file (Fig. 6). Their life-test card is then filled in (Fig. 7) with the test-condition figures and date, and the initial characteristic readings are taken upon them, after which they are placed on the life-test racks, their rack cards (Fig. 8) being clipped beside them. At the same time the works are advised by a slip (Fig. 9) that the test has begun. On the proper dates, as shown in the valve file, they are taken from the racks and their characteristics are again measured and entered on the life-test card. Let us suppose that valve 2078A fails. The works are advised on the slip shown in Fig. 10. During life the main results accumulating on the life-test are plotted on a transparent graph sheet (Fig. 11), and, at the conclusion of the life-test, blue prints of the graphs so recorded are despatched to the works. The life-test cards are filed at the Laboratories to contribute data subsequently to statistical records.

Communicated Remarks.

Mr. R. C. Clinker: The data given by the authors will prove serviceable when the time arrives for valves to be standardized. The advantage accruing to the manufacturer as a result of life-tests is indisputable, and the maintenance of a constant check on life is a necessity. As regards the design of life-testing equipment, I note that the authors have definitely adopted alternating current for filament heating, as they are mainly interested in comparative figures rather than in the life when run under normal working conditions on a d.c. filament supply. I am inclined to think, however, that they have rather overstated the difficulty of keeping a constant voltage on the filaments. For 6-volt valves it seems unnecessary to drop more than 2 volts in the common rheostat (instead of 6), and a filament failure then affects the voltage on the remainder to a much smaller extent. It is certainly desirable to avoid a multiplicity of rheostats with their possible varying contacts. The testing intervals given on page 197 seem to be somewhat long. Are these the only intervals recorded for ordinary cases? Regarding the emission measurement, although it is true that observations of R_a or I_a are wanted in practice, yet these suffer from the disadvantage that a valve or batch of valves which may change their emissions rapidly in the early stages will not show this change unless, or until, it affects the anode current at $E_g = 0$. This test, therefore, would give a poor indication as to how a valve is behaving early in its career, although giving a definite indication of the end of useful life. A brief description of one of the life-testing equipments installed in the B.T.H. Co.'s laboratory at Rugby may be of interest. All valves are run on a d.c. filament supply, as it is desired to reproduce as nearly as possible the conditions obtaining in practice. Current is obtained from accumulators which are duplicated so that one battery can be charged when the other is running. The filaments of the valves are connected in parallel in batches of 12, and in series with a common filament rheostat, the voltage of the battery being not more than 2 volts greater than the rated filament voltage. A large-capacity battery is used, and the discharge current is kept much below the normal, so that the voltage variation over considerable time-intervals is small. These small variations can be corrected and check measurements made at convenient and specified intervals. Using this method, it is possible to keep the filament voltages constant to within 1 per cent or less, except in the special case in which a filament fails by open-circuit. This is of rare occurrence in dull-emitters and, in any case, is caught within a few hours. Each batch of 12 valves is provided with separate anode resistances and can be connected by means of a plug board to a convenient tap on the anode battery, which is a potential battery of relatively large capacity. The grid bias for each batch of valves is obtained from large-capacity primary batteries connected to a suitable plug board, so that any desired voltage can be obtained. The racks for the 12 valves are laid out in such a manner that a filament rheostat can be inserted, if desired, in order to meet special conditions. The layout of one unit of this equipment, suitable for testing batches of valves with a filament rating of 6 volts, for example, consists of a central slate control panel with the necessary rheostats, instruments, switches, etc. Four racks, designed to carry 12 valves each, are mounted on each side of this control panel. The wiring to the valve racks and instruments is easily accessible for purposes of calibration and checking voltages actually on the valve pins. The latter, however, is usually only necessary on special tests where separate filament rheostats are used with each valve.

Mr. T. E. Goldup: The life-testing of thermionic valves is a subject of extreme importance to the valve manufacturer in so far as it is an indication of the quality of bulk production, and in order to obtain reliable and consistent data with regard to the life of valves, an organized scheme of life-testing, where the conditions under which life-testing is conducted are those of constant filament potential and reasonably constant anode potential, is absolutely essential. In the dull-emitting type of receiving valves, failure during life is almost invariably due to the falling-off in the total emission, therefore the observation of this particular