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RADIO SECTION

RADIO VALVE LIFE TESTING

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SUMMARY

With the rapid growth in the use of valves for electronic equipment other than for entertainment purposes, the performance given by valves during their life has assumed considerable importance. The paper gives an account of valve life-testing practice which has evolved during the past twenty-five years, and outlines possible developments which may be undertaken in the techniques used for such tests.

(1) INTRODUCTION

(1.1) The Need for Life Tests

In making a radio valve, the manufacturer endeavours to ensure that his product conforms as closely as possible to its specification. An important item in production routine is the testing of components and operations, which is carried out in order to obtain consistency of the product through control of the manufacturing processes. Final tests, conducted on a total inspection or on a sampling basis, are used to check the variability in the electrical and other parameters of finished valves. In any simple product, if the relationship between the required characteristics and the constituent parts and processes are known and properly controlled, sample testing of the final product gives the necessary assurance that its quality is satisfactory. Observation of the variability present in materials and processes is preferable to total testing of the finished product, because it removes the often lengthy and difficult task of isolating the cause of trouble when this appears in the product.

The manufacture of a radio valve involves many operations, and control of its quality is effected by means of checks made at a few stages in the manufacturing line. These checks may be made on a total or on a sampling basis and are followed by a general quality test of each finished valve.

These factors have an important bearing upon the life performance of a valve. No single initial test can predict the life which a valve may be expected to give, and experience has shown that, if a manufacturer is to market a product which he confidently feels will give a good life performance, samples must be submitted to life test throughout the production period.

(1.1.1) The Reasons for Valve Failure in Service.[1]

Emission Failure.—Theoretically, the ultimate life of a valve is reached when a large proportion of barium oxide has been evaporated from the cathode coating, resulting in loss of electron emission. In practice, valves usually fail before ultimate life is reached, through poisoning of the cathode coating by gas evolved, during life, from other electrodes.

Mechanical Defects.—Mechanical defects may indicate assembly faults which did not show on initial test. Open-circuited heaters, inter-electrode short-circuits and disconnections are typical faults which come under this heading.

Electrical Defects.—The development of leakage paths, the onset of grid emission and gas current are typical electrical defects. These are usually absent initially, but may develop during the life of the valve.

Valve manufacturers are concerned with keeping life failures to a minimum, and by running samples under controlled conditions for hundreds of hours, general life data for each type of valve are compiled, the life-test evidence being regarded as an overriding check on the whole manufacturing process.

On account of the inherently expensive nature of life testing, and the fact that considerable time must elapse before final results are reached, the conducting of regular life tests on radio valves is a matter requiring somewhat more deliberation than the decision to test other parameters. Before a manufacturer institutes a life-test service, therefore, he must form a clear idea of the information which the life tests are to provide, and what action is to be taken as a result of the information obtained.

The essential functions of the life-test department are, first, to ensure that the customer receives an acceptable level of life quality from the product, secondly, to provide the production unit with assistance in correcting manufacturing faults, and thirdly, to provide a background against which manufacturing changes and valve performance generally may be judged.

Because receiving-type valves are manufactured in large quantities, often in long production runs, they are more suited to inspection by sampling than are the small- and medium-power transmitting valves, which tend to be produced individually rather than in quantity. Inspection by sampling, if it is to yield reliable information, can be used only where the production rate is high and process variation is small.

The paper is chiefly concerned with the problems associated with the life testing of receiving valves, although the procedure used in testing small transmitting valves is outlined.

(1.2) Factors Governing Life-Test Policy

At the present time, more valves are used in domestic radio and television receivers than in any other class of equipment. Valve life in these applications is generally acceptable to the user, and a substantial extension of life would be of no great benefit. Valves are seldom the least reliable components in a radio, and receivers are scrapped or superseded with a high proportion of the original valves still serviceable. Against this background, valve manufacturers have seldom been concerned about the lives realized in service, and, on account of the time required to accumulate data on average life, it is impracticable for a manufacturer to run regular ultimate-life tests. Once the general life pattern for a type of valve has been established, it is sufficient to conduct short duration tests only, with the object of ensuring that the product is free from possible early failures.

Each type of valve may be used under many different conditions, and it is impracticable to represent them all on life test. The valve manufacturer is primarily interested in obtaining information about changes in the quality of his product, and, provided that the life tests on each type of valve are always made under the same conditions, it is less important that they accurately reproduce those obtaining in a radio receiver.

In Service, industrial and other specialized electronic equipments, valve life is usually a more important factor than it is in the domestic radio. This specialized field is one which is rapidly expanding to-day, and although the number of valves which it

The paper is a communication from the research staff of the M.-O. Valve Co., Ltd. at the G.E.C. Research Laboratories, Wembley, England.

consumes is relatively small, it is a field of considerable and growing importance. Its demands on the valve maker are often exacting and are sometimes made without regard to the limitations of manufacturing techniques.[2] Collaboration between valve users and makers is essential for a complete understanding of the problems involved.[3, 4] The requirements of valves in this class are high reliability, characteristic stability, ruggedness and long life. Equipments employing hundreds or thousands of valves are not uncommon, and failure of one valve may result in complete system breakdown unless elaborate fault equipment is incorporated. Because the objectives are different, life testing in this field requires a different approach from that usual for valves made for entertainment equipment. Accurate information may be required about very small proportions of defectives occurring perhaps after a very long life, conditions almost inevitably demanding the life-testing of large numbers of valves for a long time, and the maintenance of high precision in measurement.

(1.3) Classes of Life Test

In addition to the short-run routine tests, life tests are also necessary for pilot runs of valves incorporating changes in materials or processes. As a result of the life test and other evidence, the decision is then taken as to whether or not the proposed change may be made in the main production line.

In the later development stages of a new valve, life tests are required as part of its establishment tests, and life tests under special conditions are necessary when the suitability of a valve to an unusual application has to be determined. The main headings under which valve life-tests may be classified, therefore, are as follows:

Quality-Control Life Tests.—Quality-control life tests ensure the maintenance of the quality of the regular factory product.

Pilot-Run Life Tests.—Pilot-run life tests consist of the checking of proposed production changes before their adoption.

Establishment Life Tests.—Establishment life tests ascertain the life performance of new types of valve.

Application Life Tests.—Application life tests determine the suitability of a valve type to special operating conditions.

(2) SAMPLING

(2.1) General Considerations

The technique of controlling quality by means of sample testing is based on the mathematics of probability. Only a few relevant points can be mentioned here, and a fuller account of the methods used may be found in the literature on this subject.[5,6,7]

Statistical quality-control methods operate from two types of information obtained from samples of the process under investigation, namely data on variables (quantitative), and data on attributes (qualitative).

The first of these uses the results of measurements made on the samples, and the second uses information about the ability—or otherwise—of the samples to pass a gauge or test. The choice depends on the work and cost involved in gathering the data, but whichever method is used the objective is the same—to provide information about the bulk from examination of the sample. Control through variables generally gives the better results because it is a more sensitive technique than control through attributes. Quantitative control methods are not suited to routine valve-life-test results, however, because life expectancy cannot always be correlated with the measurement of a definite parameter.

In testing for attributes, the sample should be large enough to contain, on the average, not less than 2 or 3 defectives, and it should be noted that, for a given degree of assurance in result, sample size is more important than the proportion of the bulk tested.[8] The larger the size of the sample, the greater the degree of assurance. In other words, an increase in production rate does not call for a corresponding increase in sample size if the proportion of defectives is expected to remain unchanged. Sampling frequency, for the maintenance of production control, should be such that not too large an amount of product is made between consecutive samples. The frequency may vary, however, depending on the relative stability of the production process.

Routine 500-hour life tests on receiving valves may show the proportion of defectives from all causes to average about 1 %, depending upon the type of valve. If economic considerations are set aside, and a high degree of assurance is sought from the life-test results, then each sample should contain 100 to 300 valves, according to the average proportion of defectives expected in the bulk. For example, with a product averaging 2 % defective tested in samples of 100 valves, twice the average number of defectives (i.e. four valves) may be expected to occur once in every seven samples. If the sample size is increased to 300 valves, however, twice the average number of defectives (i.e. 12 valves) may be expected to occur only once in about 40 samples. The presence of twice the expected number of defectives in, say, the first and sixth samples would be much more significant in the sample containing 300 valves than in that containing 100 valves.

In practice, economic considerations are the determining factor in fixing the life-test sampling plan, and routine life tests cannot be considered on the basis of samples containing 100 valves. The high cost of such tests would not be met or exceeded by the reduction in manufacturing costs.

Where risks other than ordinary operational ones are involved, a high degree of valve reliability is often essential. In such cases, the user wishes to be assured of a definite life performance when buying valves, and a life-test clause may form part of the valve specification. It should be realized that no absolutely guaranteed life-expectancy can ever be given for a complex article such as a radio valve. The probability of a failure occurring before a prescribed number of hours may be very small, but the user must nevertheless reckon with the possibility of a chance failure occurring before the stated time. To the valve maker this means that, if the proportion of life defectives present in a batch of valves is to be estimated with a fair degree of certainty, life testing in samples containing some hundreds of valves will be necessary.

On account of the duration of the tests—about 3 weeks for a 500-hour run—the life-test evidence cannot provide the kind of information required for day-to-day production control, such as that obtained from the checks made on the production line. Life-test results therefore provide a commentary about the general level of the finished product rather than immediate information about any particular process or operation. The value of life-test reports lies in their cumulative evidence of successive samples.

(2.2) Sampling Procedure used in Life Testing

Life-test sampling strikes a compromise between the cost of running the tests and the value of the information obtained. The cost can easily be estimated, but the value of information obtained, particularly in a long-term view, is more difficult to assess, and the level at which the compromise should be made is found largely by experience. Life testing may be regarded as an insurance policy which is worth the small proportion of the manufacturing cost involved.

A life-test sample containing four valves taken from one day's production has been found to be a convenient unit. This is considerably smaller than that which is desirable from the statistical viewpoint, and precludes the full application of the well-developed techniques used in sampling for attributes. A single sample, by itself, is sensitive only to relatively large changes in life quality. But, when considered in the light of information from the production line, together with the evidence of previous life-test results and the trends exhibited by characteristic measurements during life test, a sample of only four valves from a month's production can be of considerable value to the manufacturer. The importance of life-test evidence being assessed by engineers familiar with valve design and production problems hardly requires emphasizing.

Sampling frequency depends upon the relative stability of the product as indicated by previous test results. A sampling plan is drawn up each month, giving the number of samples to be life-tested of each type of valve in production. A small number of samples is life-tested when the quality is satisfactory and a large number when the variability is abnormally wide. This higher sampling frequency is necessary to distinguish between an apparent and a real change in quality. The sampling plan does not always represent the sampling finally made. Both production quantity and life-test quality may be different from that expected. The occurrence of any failure is immediately reported to the manufacturing department concerned, and the sampling plan is revised when necessary. On this basis, the proportion of valves life-tested varies between about 0·01 and 0·1% of the total production, one sample a month generally being regarded as a minimum.

(3) TEST PROCEDURE

(3.1) Assessment of Life Tests

The first assessment of valves on life test is made upon their ability to pass all specified tests. At the end of the life test, each valve conforms entirely, or does not conform, to specification. Life-test results are plotted on control charts for defectives, notes on the charts giving the cause and time of each failure. This is valuable in assessing the importance of the failure, but initially it is essential that attention should be drawn to the presence of any life-test defective, no matter what the cause. Defectives are classified under the two following headings:

Catastrophic Failures.—When a catastrophic failure occurs, the defect results in the valve becoming completely inoperative.

Characteristic Failures.—When a characteristic failure occurs, the defect places the valve outside its specification, but does not render it inoperative.

The occurrence of catastrophic failures during life test are those calling for the most vigorous corrective action in the production line.

Because valves are used in a wide variety of circuits, their ability to work in any one circuit cannot be a satisfactory measurement of quality for a manufacturer. Other circuits may make other demands, and a valve which performs satisfactorily in one equipment may not work at all in another, and vice versa. Furthermore, test records often contain valuable information about fundamental valve problems which would be lost if receiver performance were the sole criterion.

A test specification is compiled, giving the measurements and limits for each type of valve, and it is upon these measurements that valve quality is based. For life-test purposes, only those characteristics likely to show a change during operation are measured, the life-test limits often being slightly wider to allow for the small changes which occur in some characteristics during life.

(3.2) Test Duration

The normal duration of life tests for receiving-type valves is 500 hours, but some types are run for 1 000–2 000 hours. A complete set of characteristic measurements is made on each valve on life test at 0, 20, 100, 200 and 500 hours. The reasons for the higher frequency of checking at the start of the test are that most valves show greater characteristic changes during the first hundred hours than subsequently, and that in some types the rate of failure appears to be slightly greater during this period.

Any valve giving signs of trouble during life test is immediately removed from the test bay and checked, without having to wait for the next normal set of measurements to fall due. If the failure is caused by a fault of relatively minor importance from the life-test viewpoint, the valve may be left to continue its life test in the normal way. Such a valve may provide valuable statistical material for other characteristic tests, and, in some cases, the recovery of a parameter which formerly was on the borderline is observed. The decision as to whether or not a defective valve should remain on life test depends upon past experience of the type in general and the value of the information obtained if testing continues.

(3.3) Life-Test Operating Conditions

This matter was referred to in Section 1.2, where it was stated that the operating conditions of valves on life test did not strictly correspond to a particular application. The policy generally followed is that of stressing the valve to its maximum rating simultaneously on as many parameters as possible, which probably represents a more severe loading than that occurring in the majority of radio receivers. Most receiving valves are run on life test at the heater voltage specified for normal operation and at maximum heater-cathode, anode and screen volts. Frequency-changers and signal diodes are tested with a fixed-frequency signal to simulate operating conditions, and power rectifiers are run dynamically.

Thermal effects are taken into account by running all valves on life test in the horizontal position, except where this is specifically prohibited. Horizontal operation represents a more severe strain both on glassware and on electrode assembly than does the customary cap-down vertical operation. Where retainers or screening cans are normally used with valves in which the electrode temperature is likely to be critical, similar retainers are fitted over valves on life test.

(3.4) Switching

Since the majority of receiving valves are used in equipment which is operated intermittently, this class of valve is subjected to regular switching during life test. In most types, the heater supply only is switched, the h.t. supply being left on continuously.

A typical switching programme is as follows:

Day (10 hours)	Continuous.
Night (14 hours)	Switched off for five minutes in each hour.

This gives nearly 23 operational hours each day, so that a 500-hour life test takes a total time of about 22 days to run, and subjects the valves to about 300 switching cycles.

(3.5) General Comments on Procedure for Receiving Valves

The foregoing notes apply in general to the life testing of receiving valves which are in regular production. The procedures used in other classes of life test (see Section 1.3) are given in later sections. The procedure described, therefore, relates to those valves which are produced in the largest numbers and which are found in almost all electronic equipment. It may be as well to recall, therefore, that each valve on life test is run at maximum rating, in a horizontal plane, it is switched at least 14 times a day and is classed as defective as soon as it fails to meet a single specified test. Many valves classed as defective on life test would work satisfactorily in radio receivers. A valve manufacturer thus regards his life-test evidence as the most pessimistic report upon his product. On that account he may sometimes be tempted to disregard unpalatable evidence, but, if the quality of the product is to be maintained, it is essential that this temptation should be resisted. On the other hand, the life-test department must ensure the veracity of the results obtained. A valve reported defective must have been a defective valve, not an over-run or a wrongly measured valve.

(3.6) Pilot Production and Establishment Life Tests

In making life tests to check the pilot run of a proposed manufacturing change, two factors must be kept in mind. First, the quantity of valves incorporating the change will probably be small. Secondly—and following from the first factor—they may contain an abnormal degree of variability in quality. This arises from the fact that a new process may involve differences in technique which may take longer to absorb fully than the pilot run allows. On the other hand, a pilot run may sometimes give slightly better results than those subsequently found when the change is introduced into the main production line. This effect may be due to increased supervision during the pilot run. In addition, a high degree of assurance that the result of the life-test sample is representative of the bulk is desirable when checking a pilot run. The effect of these factors results in the practice of submitting to life test samples larger in number than the standard four valves: 16 or more valves may be tested out of a bulk of 50–100. The actual sample size depends upon the nature of the change on trial and its probable effects on valve performance, its assessment being based upon the characteristic trends occurring during test and upon the production engineer's past experience with the valve under review. The place taken by life tests in the pilot run has been described elsewhere.[9]

The life testing of valves in the later stages of development somewhat resembles that for the pilot-run tests just described. The number of valves available for life test is usually very small, however, each valve often being an individually made sample. Quality-control techniques are not applicable to the life performance under these conditions, and the tests are run in order to discover any major design defects which may be present. The ultimate life performance of a new type cannot be obtained with certainty until the valve is in regular production and its general quality shown to be stable.

(3.7) Procedure for Transmitting Valves

The procedure used in running life tests on the smaller types of transmitting valve calls for no special comment. These valves are sometimes produced in quantities commensurate with receiving valves, and the whole of the test procedure outlined may be applied to small transmitting valves. Life tests are seldom run on a routine basis for valves having anode dissipations greater than 50 watts.

With the medium-power transmitting valves the cost of operating each valve and of providing large and special equipment is a governing factor in the decision to life-test such valves. Testing is done on a periodic-checking basis rather than by a statistical sampling one.

(4) EQUIPMENT DESIGN

(4.1) Receiving Valve Equipment

The design of life-test equipment is governed principally by considerations of reliability, operating convenience and equipment adaptability. In order that life tests may be completed as quickly as possible the equipment should be designed for continuou service and should require a minimum of supervision during night and week-end running. The fire risk present in such circumstances requires little emphasis. Operation should be simple, so that the possibility of valves being tested under incorrect conditions becomes small. The problem of equipment maintenance must be considered at the design stage, and the whole installation should be one in which its operators may take a pride in running.

It is important that the test units should be capable of testing a wide variety of valve types. Valve manufacturers usually produce only a small fraction of their complete range of types at any one time, and, if life-test facilities for every type are provided, it is obvious that a large proportion of the equipment must always be idle, unless the test units are capable of easy conversion from one type to another.

In the installation with which the author is associated, these requirements have been accommodated by building receiving-valve life-test equipment on the system of rack-and-panel units as used in telephone transmission apparatus, each bay being double-sided and accommodating up to 96 standard-type receiving valves (see Fig. 1). The valve sockets and their immediate wiring are carried on a sub-panel which is easily changed when it is required to test a different type of valve, the main

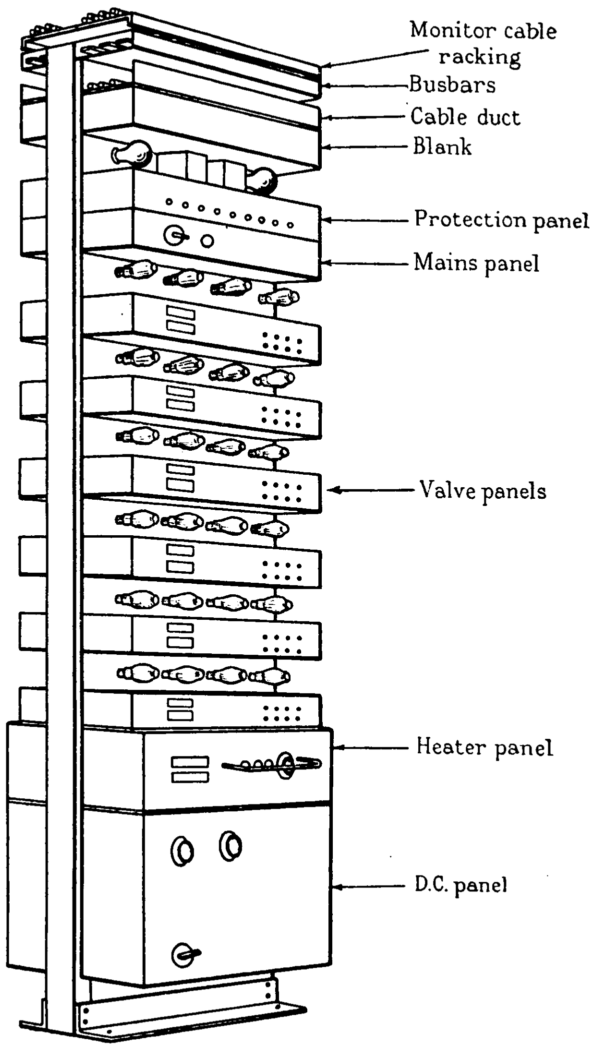

Fig. 1.—Receiving-valve life-test rack.

panel assembly and wiring remaining undisturbed. Provided that the installation has sufficient capacity to handle the total number of valves ever likely to be on life test at one time, the need for holding test facilities for valves temporarily out of production is eliminated.

(4.2) Rectifier and Transmitting Valve Equipment

In the life testing of high-voltage rectifier- and transmitting-valves, considerations of the operators' safety enter more prominently in the equipment design. Safety enclosures are used for this class of work, access to the interiors of which may be made only after the mains supplies have been disconnected.

(4.3) Monitoring

Experience has shown that it is advisable to check the operating conditions of valves on life test each day. Instrument trolleys are used for this purpose, and the daily checking provides the degree of assurance which is essential in producing life-test evidence which can be used with confidence.

In order to reduce to a minimum the time spent in manually checking valve operating conditions, an automatic method has been evolved which calls the operator's attention only to the circuits requiring correction. The apparatus is a type of "routiner" similar in design to those used in telephone engineering, its function being to show an alarm whenever the valve operating conditions of any bay exceed a predetermined tolerance.

(5) LIFE-TEST EVIDENCE

(5.1) General Results

Life-test results are best considered in terms of individual types of valve, both from the performance and from the production-engineering aspects. Grouped results may often be misleading because the sampling procedure calls for a higher proportion to be life tested when quality is inferior. Grouped results are therefore more heavily weighted in favour of the few poor types. For example, in 39 types of indirectly-heated valve submitted to a routine 500-hour test, 20 types contained not more than 0·5% defectives from all causes at the end of test. Most of the remaining types showed between 1% and 3% failures, and a small number ran for short periods with about 5% defective. Results based on the total number of failures in all valves indicated that the proportion of defectives was about 5%—a figure much too high for two-thirds of the types involved.

Among the general indications given by routine life tests it appears that emission loss due to cathode poisoning constitutes half of all failures at 500 hours. The evidence built up over many years of routine 500-hour life testing, and the information obtained from tests continued beyond this figure indicates that the survivor curve for many indirectly-heated receiving valves is approximately exponential in form, and that these types may have average lives in the region of 10 000 hours. The implications of an exponential survivor diagram on valve life have been discussed elsewhere.[10]

The reliability of valves having such a survivor curve cannot be improved by replacing all the valves in an equipment after a certain time. This practice is sometimes proposed in order to eliminate the onset of a higher failure rate which is thought to accompany lengthening valve life, a practice which is sound when the survivor curve is of the form shown in Fig. 2. This is typical of the curve obtained when failure is due to a single cause operating in the same random way each time, and in this circumstance, the risk of failure would be substantially reduced by replacing all valves after x hours' service. Radio valves having exponential survivor diagrams, however, can be made more reliable only by increasing their average and ultimate lives.

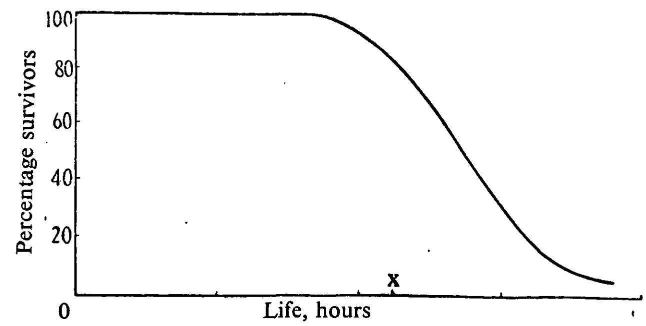

Fig. 2.—Survivor diagram where failure is due to a single cause.

Comparisons between life-test results for commercial receiving valves and those for repeater valves demonstrates the improvement in life which results from conservative rating and special manufacturing procedures. Fig. 3 shows a survivor diagram for

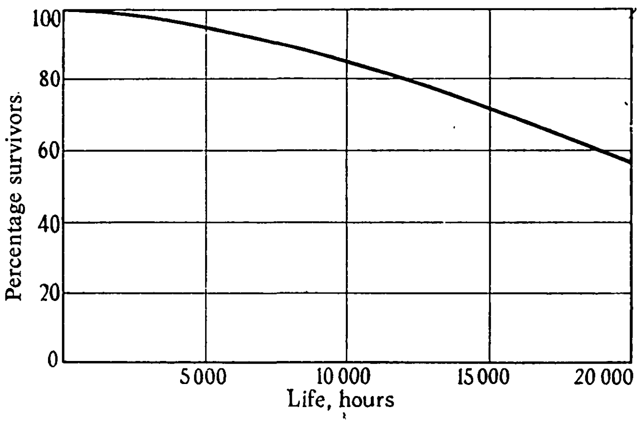

Fig. 3.—Survivor diagram for repeater valves.

a typical repeater valve and may be compared with similar curves which have been published.[11]

The effect of switching upon life does not always appear to be as harmful as is sometimes stated. Samples of B36 double-triodes and Z77 miniature pentodes, run both on switched and on continuous life tests, have shown no significant difference in performance over several thousand hours. It is of interest to note that the same result was found in batches of valves with 0·1-amp heaters, and that such valves showed no greater tendency towards heater failure than did the well established Octal range employing 0·3-amp heaters.

(5.2) Future Developments

The fundamental problem of all life testing, and especially that of radio valves, is the development of reliable techniques for accelerating the life test. This has proved to be a difficult matter and no satisfactory method has yet been evolved.[12] Two approaches to the problem are possible; the first is to speed up the processes within the valve which ultimately lead to its failure, and the second is to establish a correlation between the measurement of some parameter during life and the cause of ultimate failure. The establishment of such a correlation would make reliable forecasting practicable.

Under the first heading, the practice of overloading valves on life test is a solution which may be offered. This is extensively employed in life-testing metal-filament lamps where the practice effects a considerable saving of time.[13] This type of lamp nearly always fails for one reason, its designed life is of the order of 1 000 hours, and life tests at normal rating take about six weeks to complete. Overload tests reduce this time to about 20 hours, so that the accelerated life test provides a day-by-day commentary on general product quality. But even in this application, the accelerated life test is valid only for the predominant fault—filament failure—and no speeding-up process has been established for gas leakage and other faults.

By comparison, a radio receiving-valve is subject to a relatively wide variety of faults which determine its life, and it is well known that attempts to increase the rate of fault occurrence by overload tests may not have a consistent effect on the life performance. Increased cathode temperature, while reducing its theoretical life, may, in fact, improve the realized life by increasing the cathode's resistance to gas poisoning. Similar effects are present when valves are run below their normal cathode temperature, and it appears unlikely that a reliable correlation can be found between results of tests run at different cathode temperatures.

A more promising field for decreasing life-testing time exists in the development of critical measuring techniques. Work based upon the accurate measurement of total cathode emission during life shows promise of fulfilling some requirements in this field. If life performance could be reliably correlated with a measured parameter, such as total emission, this would permit the application of better statistical assessment through the observation of variables. The superiority of variables over attributes in statistical work was mentioned in Section 2.1.

These possible developments, however, would offer little help in forecasting the incidence of electrical and mechanical defects during life. Carefully designed vibration tests may be of value in revealing inherent mechanical weaknesses in a valve, but it is obvious that such tests may be deceptive, because, in addition to revealing incipient faults, they could produce defects which might never occur at all in normal service. Distinction should be made between vibration tests proposed as accelerated life tests—tests intended to reduce the time for an inherent fault to be made manifest—and vibration tests intended to determine the suitability of a valve to a particular application. A preliminary to the establishment of a satisfactory vibration-test technique would appear to be the formulation of a precise definition of vibration and a specification for its measurement. To define only the manner in which a vibration test is to be conducted is insufficient. This might result in differences in valve performance owing to unknown differences in two apparently similar test-equipments. Definition and measurement of vibration would also be required if the vibration experienced by, say, an aircraft radio equipment were to be used as data in setting up an equivalent valve life-test schedule.

In addition to work on life-test techniques, some considerations should be given to the standardization of the life-testing procedure for radio valves. Standardization, such as has been adopted for electric-lamp[14] and dry-battery[15] life testing, would facilitate the exchange of information about the life performance of valves, and assist in understanding the problems involved in improving their reliability. Aspects upon which some general agreement should be reached include the operating schedules for life tests, the form of expressing life-test results and the basis of assessing the end-point. The latter subject has already been mentioned and is one inevitably involving a compromise. End point should clearly be related to application conditions which involve a wide variety of criteria, and the task of choosing the value which a valve parameter must reach before constituting a failure may be a matter of some difficulty. Life-test limits which are too narrow result in an unnecessarily high proportion of defectives being reported; on the other hand, limits set too wide may result in a product of inferior quality reaching the market. The definition of end-point is clearly a factor of considerable importance in comparing life test evidence. Finally, from the user's viewpoint, information about the effects of ambient temperature, switching, vibration and storage upon the reliability and life of valves would be of considerable value.

(6) ACKNOWLEDGMENT

In conclusion, the author desires to tender his acknowledgments to the M.-O. Valve Co., Ltd., on whose behalf the work described in the paper was carried out.

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DISCUSSION BEFORE THE RADIO SECTION, 7TH FEBRUARY, 1951

Mr. H. G. Hughes: The author emphasizes the importance of life-test evidence being assessed by engineers familiar with valve design and production problems, and I whole-heartedly agree. In my organization we frequently get defective valves returned with explanatory statements of what has happened to them, and more often than not the story is quite useless for diagnosing the true cause of failure. I do not wish to discourage engineers from giving their views on causes of failure, but I do ask them to realize that they can give the most valuable assistance if they will first describe carefully what actual symptoms of failure were observed.

Valve manufacturers ask us to send back defective valves together with records of their lives, but we just cannot do it to any appreciable extent. It seems strange that the Services, who use thousands of valves a month, cannot supply reliable inforquestion of switched and continuous life, I should like to mention the results of some vibration tests which have been carried out to determine heater life.

One test involved about 100 valves operated at a heater voltage of 7·5 volts, and the other about 60 valves operated at 6·3 volts. One half of the valves in each case were switched, five minutes on and five minutes off, while the other half were run continuously. Failure-rate curves were plotted for both tests, and in the case of the 6·3-volt test the failure rate for the continuously operated valves was about three times that of the switched ones. In the case of the 7·5-volt test, after a delay of about one hour during which the switched valve failures were very low, the failure rate was about the same for switched and continuous running. The fact that both tests gave failure-rate curves of almost the same shape suggests that the number of valves involved was too small to show any difference between 6·3-volt and the 7·5-volt running. All that was proved, in fact, was that continuous running was rather more injurious than switching under these particular operating conditions. Any statement on heater life under switched or continuous operation is useless unless one states the exact operating conditions and the type of valve. It is fairly generally agreed that the user finds switching to be injurious under certain conditions, but if he operates under vibration conditions he may find the reverse effect to be the case.

Mr. W. H. Aldous: I should like to refer to the life-testing of amplifier valves under operating conditions, more particularly at high frequencies. To do this adequately, the driver valve should be such that its life is several times that of the valve under test, to ensure that the driving power remains constant. For life testing of experimental valves, such driver valves are often difficult to obtain, since the purpose of the experimental work may be to develop power at a frequency or at a level that has not been reached before.

A further difficulty at high frequencies is the provision of circuits which will be simple to set up and at the same time be free from mechanical troubles when run continuously for thousands of hours. When concentric-line circuits are used, particular care must be taken that dirt does not cause trouble with the sliding-finger contacts.

With regard to the switching of heater supplies, both on life test and in general use, there is one point which is too often overlooked, namely the high ratio of hot-to-cold resistance of the heater. With a heater supply of good regulation, the initial current surge can be very high, and the exposed parts of the heater can be taken to an excessive temperature. To avoid troubles from this cause, heater supplies should be designed to have poor regulation.

Reference has been made by previous speakers to valve specifications. It should be emphasized that the normal practice with regard to the parameters that vary during life is to set the lower specification limits well above the point where the valve would fail to operate. A valve passed out on this lower limit should then still have an adequate life.

THE AUTHOR'S REPLY TO THE ABOVE DISCUSSION

Mr. R. Brewer (*in reply*): Whilst agreeing with Mr. Rowe that life-test evidence and field reports should tell the same story, I believe that the operating conditions for valves on life test should be on the severe side. It is true that routine life tests may not be appropriate for some conditions of usage, but this does not detract from the achievement of their primary object, which is to assist in maintaining the general quality of the product. Application life tests are intended to check the suitability of a valve type to special service conditions, and in some circumstances samples may be submitted regularly to these special tests.

In answer to Mr. Fry's question about heater voltage, I regard the larger quantity of data from one test condition as being more valuable than smaller quantities from each of several conditions. It is very difficult to form a clear impression of the way in which valves behave during life unless the number of test variables is kept small.

I agree with Mr. Hitchcox on the definition of end-point, and I class a valve as defective when it exceeds the limit on any one of some six tests. Life-test limits are the same as acceptance-test limits on most parameters, but they may be slightly wider on the remainder. Moreover, as Mr. Aldous has said, the lower limit is well within the normal operational range of the valve. The American JAN—1A Specifications define life-test end-point in terms of one or two parameters only, the tolerances being wider than the acceptance-test tolerances by varying proportions.

The physical examination of a valve enables us to form only a rough idea of the length of time it has been in service. All valves failing on life test are carefully examined, but we also break open many survivors, the examination of which has some bearing upon the point which Brig. Moppett has raised.

On the difficult subject of reliability factors, I agree that it would be unwise to apply them to valves as types. It would be essential for the factor to be derived individually by each manufacturer producing the same type of valve.

If the mechanical-breakdown test proposed by Mr. Hitchcox involves the element of time, then M and L are two aspects of the same thing. The two interdependent properties for which these tests are proposed, in fact, constitute the mechanical and electrical conditions under which the valve ultimately fails. Results of mechanical tests depend largely upon the length of testing time, and their first effects may be the development of electrical faults rather than complete mechanical breakdown.

A modified form of Dr. Metson's reliability factor which we have used defines P as the average number of valves that would have to be tested to find one failure in 1 000 hours. Such a factor immediately indicates the magnitude (and cost) of the life-test task necessary to establish a given standard of reliability, and it is easily modified to find the sample sizes necessary for different degrees of certainty in the result. The fact that reliability increases with factor number is better psychologically, and the avoidance of fractional values of P also seems an advantage.

In attempting to forecast valve life, both low-temperature and pulse-emission measurements are used, the current density for the latter being of the same order as that used by Mr. Fry.

In reply to Mr. MacNee's question about the routiner, this is used for checking valve running conditions.