Valve Life

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Despite the recent development of the transistor it is likely that the thermionic valve will continue to be the mainstay of the electronic industry during the foreseeable future, and its use is becoming even more widespread. The importance of designing and manufacturing more reliable valves is therefore greater than it has ever been. In this article Dr. Metson, of the Post Office Engineering Research Station at Dollis Hill, London, reviews recent work on the causes and remedies of valve failure. The article is based on a paper[1] entitled "A Study of the Long-Term Emission Behaviour of an Oxide-Cathode Valve," which was published in the September issue of the Proceedings, Part B.

THE growth of activity in electronic engineering during the past ten years has stimulated interest in the life and reliability of thermionic valves—literature on the subject during the past five years probably exceeds that of all previous time. Despite recent progress, however, the problems of valve failure are still only partially understood, and the present article attempts no more than a broad appreciation of the art as it appears to stand to-day.

The valve most commonly used in general electronic work is the high-vacuum indirectly-heated oxide-coated-cathode type in diode, triode or pentode form. In the interests of efficiency such valves have tended to become smaller in physical size and more economical in heater power—the four-watt cathode, so prevalent in the Second World War, is now displaced by the two-watt version with little change of valve performance, and the trend has not yet ceased. There can be little doubt that this steady improvement of performance has made the task of increasing life rather more formidable.

"Valve failure" is a generic term and covers all changes in the valve of sufficient magnitude to cause intolerable changes in the external circuits. It has become fashionable to separate these changes into two classes—mechanical failure and electrical failure. Generally speaking, mechanical failure is characterized by abrupt cessation of valve action whereas electrical failure is more in the nature of a decay phenomenon. The two forms carry different weight in different spheres of use; the mechanical form is fearful to the aircraft engineer whilst the communication engineer is more concerned with the decay phenomenon with its insidious and indefinite approach to an end point. They are, however, not always clearly distinguishable and there are known conditions under which mechanical faults cause electrical failure, and vice versa.

Mechanical Failure

Perhaps the most marked characteristic of mechanical failure is its enhanced probability of occurrence when the valve comes under mechanical load. The increasing use and importance of valves in mobile stations on land, at sea and in the air have therefore led to a first concentration of effort on mechanical failure. This work has been pressed forward with great vigour since the war, and a short range of common-usage valves of inherent mechanical reliability is now becoming available. Progress has been made along two general lines—a study of the basic properties of materials affecting mechanical reliability and a thorough-going investigation into the relation of structure to strength under conditions of shock and vibration. Notable papers on these advances have been written recently by O'Donnell Roberts[2] and by Rowe and his associates.[3]

Electrical Failure

Whilst the main effort has so far concentrated on mechanical failure, the electrical aspects have not been altogether neglected and some modest but sound progress can be reported. Electrical failure covers a variety of forms and the simultaneous presence of several such factors in a valve has led to confusion and difficulty in interpretation. Perhaps the most solid achievement during the past ten years has been the development of techniques for separating and measuring these effects in such a way that it is now becoming possible to relate individual effects to particular causes. It is becoming clear, for example, that most electrical faults in a valve originate from microchemical actions in the oxide-coated cathode itself. The present section will attempt to outline the broad nature of these actions.

The cathode consists of a granular matrix of barium and strontium oxides deposited on a hollow metallic core which contains the insulated heater. The essential electron flow must therefore pass from the core into and through the matrix and out again into the vacuum. The hot matrix must therefore conduct and emit electrons in adequate quantity and it can do so only if it contains an excess of the metal barium. From the point of view of useful valve action a perfect lattice of barium and strontium oxides is a non-conductor and non-emitter but adulteration of the lattice with a trace of metallic barium renders it a strong conductor and excellent emitter. The basic problem of cathode life is therefore the initial provision and subsequent maintenance of an adequate level of excess metallic barium. The source of barium is clearly the molecular matrix itself and this must be split by removal of the oxygen atom. There are two obvious ways of effecting the split—by the introduction of elements chemically capable of wresting the oxygen atom from the oxide molecule, and by direct electrolysis of the molecule. Extensive use of the first method is made in common valves, and typical reducing agents employed are magnesium and silicon, which are included as activators in the nickel core metal. The reactions involved are:

$$Mg + BaO = MgO + Ba \qquad (1)$$

$$Si + 4BaO = Ba_2SiO_4 + 2Ba \qquad (2)$$

Since the activators are limited in quantity and perform chemical work they are subject to inevitable decay. A cathode wholly dependent on activators for its excess barium is therefore living on capital and must fail in time owing to lack of emission. It is at this stage that the electrolytic mechanism becomes important as, depending only on current flow, it continues supplying the essential barium. An obvious question now arises—why not rely wholly on electrolysis and dispense with the reduction method and its attendant decay? The answer is an economic one. The price of a valve has a direct relationship to the quality of its vacuum and most valves in common usage enter service with an undesirably high level of residual gas content. Under the action of the getters this high initial residual pressure falls with time but during this early period of life the excess barium in the cathode is open to destruction by gas oxidation. It is the prime duty of the activators to nullify this attack by matching a destruction with a production rate. Ideally, the two rates should balance each other to extinction over a period of time, leaving the mild electrolytic action to the long-term task of supplying excess barium to the matrix. If the valve is provided initially with a vacuum of sufficient quality it is possible, of course, to dispense with the activators, but such valves can at present be produced only at high cost. This description of cathode action is over-simplified but the author hopes that it will suffice for the purpose of understanding the principal causes of electrical failure in valves.

The decay of mutual conductance with time is probably the most serious of the electrical forms of failure. It is due to two separate and distinct causes—oxidation of excess barium in the cathode leading to emission failure, and growth of a high-resistance interface between matrix and core. The first cause is clearly the destruction rate of barium by residual gas exceeding the production rate by the activators over a sufficient period of time. Symptoms of failure are a fall in mutual conductance and an increase in valve noise due to inadequate emission. The second cause is the formation of a layer of barium orthosilicate between matrix and core during valve manufacture—the chemical reaction will be clear from eqn. (2). When the valve enters service the layer is highly active owing to the presence of excess barium atoms and its resistance is normally less than an ohm. As the layer loses excess barium by gas action or diffusion to other parts of the matrix, its resistance rises and may reach 50 or even 150 ohms for a two-watt core. The negative-feedback action of this resistance results in substantial degradation of mutual conductance. These two actions are at present thought to account for most cases of mutual-conductance failure.

Most other causes of electrical failure are connected in some way with the evaporation of active metals such as magnesium and barium from either anode or cathode. During manufacture and under operating conditions some evaporation of barium oxide occurs and results in the formation of barium-oxide films on the mica insulating surface of the electrode structure. These films have little effect until they become activated by barium evaporated from the cathode or magnesium from the anode. On activation the films show conductance and give rise to a considerable range of valve troubles—leakage between electrodes causing intermittent noise, growth of inter-electrode capacitance, etc. Most of these evaporation effects can be avoided by shadowing the surfaces of the insulators from anode and cathode, and such methods will doubtless be used as new valves are designed.

Natural Life Span

Almost all valves fail in service from causes which appear to be capable of remedy. If the core material is designed to avoid interface-resistance growth, if the structure is freed from all residual gas, and if steps are taken to avoid contamination of insulating surfaces, the valve should run for a natural life-span which is based on some fundamental property of the cathode material used; in short, life should be predictable and calculable. At present the art is far removed from this desirable state and the best that has been achieved is to show that the length of life does in fact increase as we approach the conditions outlined above.

In a recent paper[1] an attempt has been made to survey this problem of natural life. It is assumed that life will continue so long as an adequate amount of oxide remains on the core and this oxide retains a sufficiency of excess barium metal. The rate of loss of the oxide itself by thermal evaporation is calculable and twenty years of running at the conventional cathode temperature should have little material effect on the gross bulk of the matrix. The real problem therefore hinges on the continued ability of the matrix to maintain an adequate level of excess barium within its lattice. This aspect is examined in some detail in the paper, which comes to the tentative conclusion that electrolysis of the matrix takes place at a sufficient rate to keep it adequately stocked with excess barium metal. The oxygen gas continually drawn from the cathode as an electrolytic by-product must of course be prevented from returning to the cathode; otherwise the whole electrolytic activation will be negated. If such preventive arrangement can be made and if no other residual gases are generated during operation there appears to be reasonable hope that valve life may be indefinitely prolonged. The main obstacle at present is the technological difficulty of maintaining an adequate vacuum during normal operation.

References

1 METSON, G. H.: "A Study of the Long-Term Emission Behaviour of an Oxide-Cathode Valve," *Proceedings I.E.E.*, Paper No. 1790 R, April 1955 (**102 B**, p. 657).

2 O'DONNELL ROBERTS, E. A.: "A Study of Some of the Properties of Materials affecting Valve Reliability," *Proceedings I.E.E.*, Paper No. 1645 R, February 1954 (**101**, Part III, p. 197).

3 ROWE, E. G., WELCH, P., and WRIGHT, W. W.: "Thermionic Valves of Improved Quality for Government and Industrial Purposes," *Proceedings I.E.E.*, Paper No. 1740 R, December 1954 (**102 B**, p. 343).