SOME FACTORS AFFECTING TRANSMITTING VALVE LIFE*

by

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SUMMARY

A knowledge of the principles underlying the operation of vacuum tubes enables a user to appreciate what performance may be expected and to understand to what extent factors under his control may influence the life obtained. The object of the paper is to discuss briefly the principal factors which affect valve life, and to do this it is convenient to study the various modes of failure. A number of good operating policies will become evident as the reasons for failure are studied, and these will be stated as the occasion arises. Emission and filament failures in valves with pure tungsten filaments, thoriated tungsten filaments and oxide-coated cathodes are dealt with first. A few remarks are then made about glass failures and operating temperatures. Mechanical failures are mentioned very briefly, and finally certain important factors relating to storage and handling of valves are dealt with.

1. Emission and Filament Failures

1.1. *Valves with Pure Tungsten Filaments*

In this case the emission is simply that from a pure metal. The operating temperature is so high that contaminants are quickly removed, and the phenomenon of poisoning so frequent with other types of emitter is rarely observed. Gas has practically no effect on the emission from pure tungsten, but on the other hand pure tungsten at very high temperatures has the ability to take up very large volumes of gas as it is released in the tube or as it enters the tube by way of infinitesimal leaks. Gas failures, therefore, are relatively uncommon and life is more usually terminated by burn-out of the filament.

The temperature at which the filament is operated is limited by evaporation of the tungsten. As the operating temperature is increased, so also is the rate of evaporation of the metal. As the metal is evaporated, the cross-sectional area of the filament is reduced. At those parts where the temperature is highest, the reduction in cross-sectional area is obviously greatest, and thus there is a tendency for a further increase in temperature and evaporation rate. This effect is counteracted by conductivity along the wire which tends to keep the temperature uniform. It is found, in general, that by the time the cross-sectional area of the filament has been reduced to about 90 per cent of its original value, the irregularities in diameter are such that temperature irregularities become serious. At the thinnest point the temperature rise rises, the evaporation rate increases, the wire "necks down," the tungsten at the centre of the reduced area melts and surface tension causes the tungsten to draw up into a droplet on one or other of the limbs of the filament, thus producing an open circuit.

The emission available from a filament is a function of surface temperature and surface area. Life is determined only by temperature and thus very long life could be obtained by producing a valve with a filament of large surface area operating at low temperature. Such a filament requires high heating power. A reduction of heating power requires a smaller, higher temperature filament, which obviously will give a shorter life. The size of a filament and thus the life it will give at full ratings has to be determined on economic grounds.

Figure 1 shows curves of the percentage life and emission against filament voltage expressed as a percentage of the normal value. These curves are based on normally chosen operating temperatures. It will be seen that life is greatly increased as filament voltage is reduced. In particular, at 90 per cent of normal voltage a four-fold increase in life is obtained, but of course the available emission is reduced to 45 per cent of normal.

It frequently happens that a valve chosen for a particular job has a greater reserve of

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emission than necessary for satisfactory operation. If the valve has a pure tungsten filament it should be used at as low a filament voltage as is consistent with satisfactory operation. In Fig. 2 is shown the burnt-out filament structure of a type 4220Z water-cooled, pure

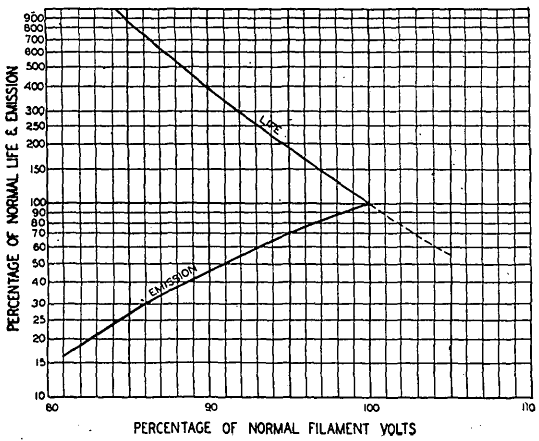


Fig. 1.—*The percentage of normal life and emission plotted as a function of the percentage of normal filament voltage.*

tungsten filament valve. It was operated in an equipment where there was a considerable reserve of emission so that the filament voltage could be reduced to 90 per cent of the normal rated value. The life obtained was 27,590 hours, which compares with 6,000 to 7,000 hours, usually obtained with valves of this type when operated at maximum ratings. Fig. 2*b* shows a greatly enlarged view of the burn-out. The necking-down of the filament and the formation of a droplet of tungsten on one of the limbs can be seen clearly.

The resistance of a hot tungsten filament is approximately fifteen times that of a cold filament and as a result care must be taken to limit the starting current when lighting up a filament, as otherwise the mechanical forces resulting from the high magnetic field associated with the filament current may distort or, in extreme cases, even shatter the filament. Normally a limit of about 70 per cent above the normal operating current is imposed as a maximum starting current. In addition, in order to reduce the effects of thermal shock on the filament and its supports, it is desirable to reduce to a minimum the number of times the filament is subjected to switching stresses. For the same reason, it is usual to recommend that during stand-by periods of up to two hours, the filament voltage be maintained at 80 per cent of normal. At this figure the evaporation rate is negligible, so that without appreciably affecting the life of the valve, the filament is protected from the effects of thermal shock.

As an example of the serious damage which can be caused by excessive filament starting current, Fig. 3 shows an x-ray photograph of the elements of a 4220Z valve which failed in an industrial equipment after 1500 hours. In the first place it was found that the starting current was over 100 per cent above normal and even more important, the filament was switched on and off as many as thirty times per day. Failure was caused by contact between filament and grid.

1.2. *Valves with Thoriated Tungsten Filaments*

In this case, emission depends on the maintenance on the surface of the filament of a layer of thorium atoms. The operating temperature is considerably above the melting point of thorium, but a unimolecular layer can be maintained provided the operating temperature is held within very rigid limits.

One condition necessary to the maintenance of this layer is that the diffusion rate of thorium from the body of the wire to the surface must be sufficiently high. The diffusion rate increases with temperature, but of course so does evaporation from the surface. In order to achieve the required diffusion rate at a suitable temperature, the outer layers of the wire are converted to tungsten carbide through which thorium diffuses more rapidly than through tungsten. Unfortunately tungsten carbide is extremely brittle so the layer converted to tungsten carbide contributes little to the mechanical strength of the filament. Usually about 20 to 30 per cent of the cross-sectional area of the wire is converted to carbide. The operating temperature of a thoriated tungsten filament is usually about 2000°K as compared with about 2500°K for a pure tungsten filament. Evaporation of tungsten is negligible at this temperature so that the mechanical life of a thoriated tungsten filament is potentially very great. Also the amount of thorium consumed during the life is a negligible part of that contained in the wire. Permanent failure of emission in this case usually occurs as a result of decarbonization, which takes place at a rate depending on both temperature and gas pressure.

If a thoriated tungsten filament is operated at too high a temperature, decarbonization takes place at a greatly accelerated rate and permanent, early loss of emission results. If the temperature is too low, the thorium layer may not be maintained and loss of emission result. In this case, however, reactivation may be possible, provided there is no secondary damage.

The widest tolerable limits of filament voltage for this type of valve are $\pm$ 5 per cent but improved life is usually obtained if closer control can be maintained.

1.3. *Valves with Oxide-Coated Cathodes*

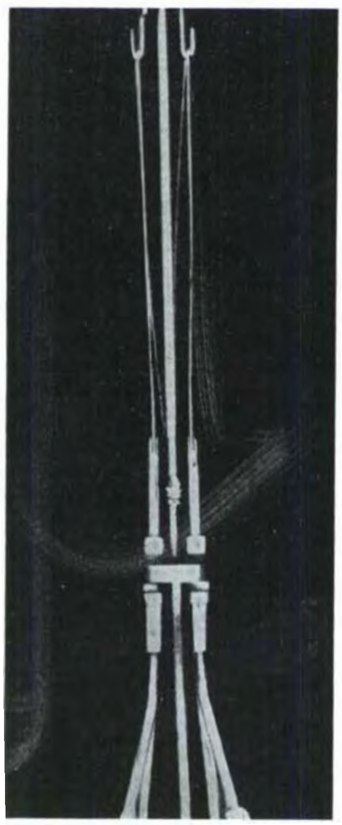
The mechanism of emission in this case is extremely complex and to obtain successful results a very delicate balance has to be maintained between various temperature sensitive processes. The permissible operating temperature range is quite narrow.

In general, the life of an oxide-coated cathode if operated within the correct temperature range is so great that very rarely indeed is it the primary cause of failure. Loss of emission frequently occurs, but almost invariably this is the result of an increase of gas pressure within the valve, of mechanical damage to the coating, or of poisoning by some contaminant.

1.4. *General*

Filament and emission failures may be called fundamental limitations to the life of a valve. We have seen that valves with pure tungsten filaments frequently reach their full potential life, which is determined only by filament operating temperature and is terminated by mechanical failure. In cases where there is more reserve of emission available than necessary for satisfactory performance, great improvement in life may be obtained by reducing the filament voltage.

In the case of thoriated tungsten filaments,



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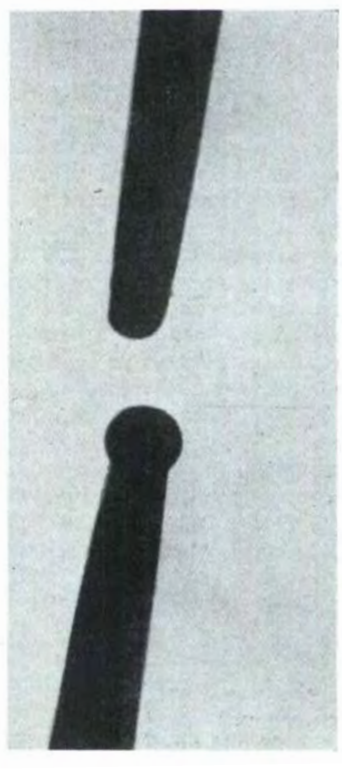

(*b*)

Fig. 2 (a)—The burnt-out tungsten filament of a 4220Z water-cooled valve. (b) An enlarged view of the burnt-out filament.

potential lives are generally much longer, but to achieve the greater potential life the operating temperature must be maintained strictly within the correct range and gas pressure must remain low. It is frequently found that faults other than emission are the primary cause of failure with these valves.

The life of a valve with an oxide-coated cathode may be terminated by any one of a large number of faults. Provided the cathode is operated within the narrow range of temperature set by the manufacturer and provided gas pressure remains very low, cathode life is so long that it can be regarded as almost indefinite.

In the case of valves with thoriated tungsten filaments and oxide-coated cathodes, life is determined not only by filament temperature but also by operating gas pressure and anode voltage. Anode dissipation and glass temperature, therefore, as they affect gas pressure, are also important factors in determining valve life.

2. Glass Failures

All the valves referred to in this paper use glass envelopes with connections made to electrodes by way of metal to glass seals. Inevitably, the walls of any irregularly shaped, evacuated vessel are stressed, and the stresses are accentuated by the presence of the metal to glass seals. In operation, the leads sealed through the glass are heated by the currents flowing in them and the glass is heated by the radiation from the internal electrodes. Temperature gradients are thus set up when the valve is in operation, so that stress patterns are different in a hot valve from those in a cold valve.

Generally speaking it is not possible to produce a metal to glass seal that is completely stress free. What has to be done by the manufacturer is to produce a valve in which stresses in the various parts of the envelope are safe at room temperature and under operating conditions. Photo-elastic methods are used to reveal the position and magnitude of stresses and rigid inspection procedures are necessary to control production.

The bond between the metal and glass of a vacuum tight seal is a layer of oxide of the metal, which adheres very strongly to the metal and part of which dissolves in the glass. This bond is quite stable over very long periods provided the temperature is not excessive and provided it is not subject to electrolysis or attack by moisture or other active agents.

The most common modes of failure of the glass work in a valve are the development of a crack, or the destruction of seals by prolonged overheating, frequently in combination with electrolytic action. The conductivity of glass is normally very low indeed, but it increases rapidly with temperature. In operation, therefore, the glass acts as an electrolyte and the various leads, where they are sealed through the glass, act as electrodes. The products of electrolysis are deposited at the metal surface of the seals. It is, of course, to the most negative

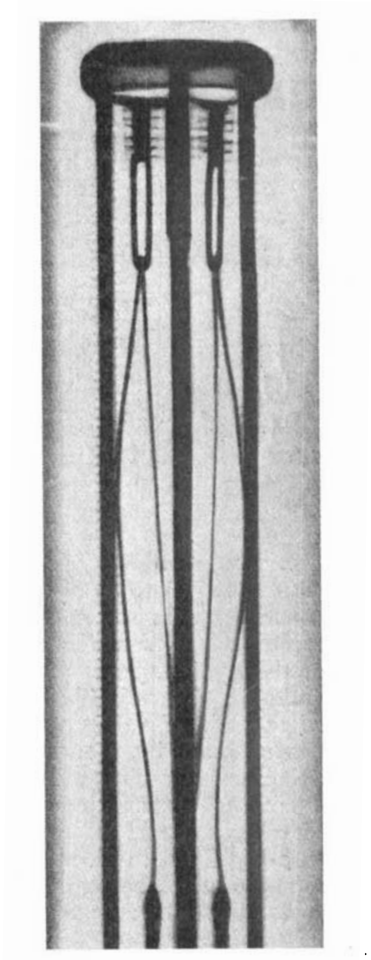

Fig. 3.—An X-ray photograph of the filament of a 4220Z valve distorted by frequent, excessive starting current.

electrode that any hydrogen or metal ions migrate and this is the seal usually most affected. If the process continues long enough (or fast enough) the metal to glass bond is attacked and high stresses may be built up. Sudden failure may result either by destruction of the vacuum tight seal or by development of a crack. In extreme cases failure may occur from this cause in a few hundred hours, but it is not uncommon to find serious attack on seals after 3,000–4,000 hours operation with barely adequate cooling.

3. Temperature of Operation

It cannot be too strongly stressed that the longest life will be obtained from a valve only if the utmost care is taken to keep the operating temperatures of the glass and leads to a minimum. The requirement for care in the establishment of operating conditions is obvious, as this determines working voltages and internal electrode temperatures. Having established suitable operating conditions, considerable variation of life is possible depending on the efficiency of the cooling systems employed. This is true for all types of valve, whether they be radiation cooled, forced air or water cooled.

An increase in glass temperature frequently involves an increase in stresses which may become dangerous, invariably accelerates electrolytic action, and in spite of the rigorous pumping to which valves are subjected, results in the liberation of gas from the envelope and hence raises the operating gas pressure. This last, as mentioned above, has a very marked influence on the life of valves with thoriated tungsten or oxide-coated cathodes. The maximum operating temperatures which might be considered safe for transmitting valves using hard glass envelopes are 250°C for those parts of the bulb away from any seals and 150°C for the glass adjacent to any seal.

We have found that crayons made with temperature sensitive pigments give reliable indications of temperature to an accuracy of about ± 10 per cent. They are certainly much simpler to use in the presence of strong r.f. fields than other methods.

4. Mechanical Failures

Space does not permit more than a passing reference to failures of this nature. A good deal of the manufacturer's effort is directed towards strengthening and improving mechanical construction of valves. Rigid control of materials and methods, together with careful inspection are essential, but the state of the art is still such that a valve is a fragile article which requires careful handling. The user must take every reasonable precaution to avoid undue shock and vibration.

5. Storage and Handling of Valves

Valves should be stored in a dry place, away from exposure to sunlight, which as well as having a weathering action on glass can cause unnecessary and even dangerous temperature cycling.

If a valve is warm it should never be subjected to thermal shock by being placed on a cool heat conducting surface.

Great care should always be exercised to avoid scratching the glass, as a scratch in a highly stressed area of the envelope may initiate a crack or even cause an implosion.

Valves tend to deteriorate if left on the shelf too long. The reason for this is two-fold. The attack on seals by moisture has been mentioned already, but infinitesimal leaks and liberation of gas internally, also result in an increase of gas pressure. When the valve is in operation these minute quantities of gas are continuously being taken up by the gettering action of electrodes and the operating pressure remains very low. On the other hand, if the valve is left for very long periods without use, when at last it is put into service, the amount of gas which has collected in the envelope may be sufficient to damage the filament or cathode permanently before it can be taken up. This danger may be countered by operating the valve at regular intervals no longer apart than say three months. Suitable conditions for taking up residual gas may be obtained by interchanging spare and working valves, so that the spare is given at least one hour of operation—preferably more. If this is not possible, simple ageing equipment is sometimes constructed so that suitable conditions can be applied.

Unfortunately there is no way in which damage caused by the effect of moisture on a seal can be repaired, A good deal of work is being done however on the use of protective coatings and moisture barrier packages to overcome this trouble and to make storage of valves, particularly in sub-tropical conditions less hazardous.