The causes of burnout of incandescent lamp filament

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The experimental investigation concerning burnout phenomena of double coiled filaments in incandescent lamps was performed. Though most of the initial hot spots in filaments observed by current pulse burning are due to diameter defects, they are not main causes of burnout. The correlation between the initially highest temperature portion burning on steady current and burnout position is high. The evidence that the irregularity of temperature distribution caused by pitch defect have bad influence on life of lamp was found.

1. Introduction

Many studies of burnout phenomena of tungsten filament in an incandescent lamp have been based on the hot spot model. According to this model, at the beginning of life there is a small defect of the filament which becomes to be slightly higher temperature than the rest part of the filament, and the higher temperature causes faster evaporation of tungsten and failure occurs when the temperature reaches to the melting point.

It has been suggested in several reports\textsuperscript{1-3} that the defect which has caused the initial temperature rise has been usually a local decrease in wire diameter or in coil pitch parameter. Covington\textsuperscript{4} and Baker\textsuperscript{5} treated theoretically the burnout of single coiled filament containing hot spots caused by wire diameter defect and coil pitch defect. Dawson et al.\textsuperscript{6} showed experimentally that hot spots of filament grew during burning and controlled the life of lamp using a current pulsing technique introduced by Davies\textsuperscript{7}.

Although the role of hot spots in controlling the life of incandescent lamp has been recognized, knowledge concerning hot spot is not so clear. The present study was undertaken to examine more about the cause of hot spot. Using current pulsing technique and steady current method which is to measure the temperature distribution along filaments burned on steady current, the hot spots on double coiled filaments were examined. The experimental results show the evidence that primary and secondary coil pitch defects have more important effects to filament burnout than wire diameter defects.

2. Experimental procedure

The sample filaments used were double coiled filaments mounted horizontally in conventional 100 V 40 W gas filled incandescent lamps. The wire diameter was 0.045 mm and filling gas was argon-nitrogen mixture.

The first step observation of hot spots was performed by current pulsing technique. The pulse current was generated by capacitor discharge, pulse height being 5,40 V and pulse width being about 2,2 msec. Hot spot patterns of filament were photographically recorded.

The second step observation was performed on steady current method. The filament was burned on steady dc current and the light passing through a rotating slit was received by photomultiplier, the output of which was displayed on an oscilloscope through a digital memory. The block diagram of this apparatus is shown in Fig. 1. Scanning time along the filament was 2 seconds. The output signal had been calibrated previously for temperature by the aid of a pyrometer.

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Fig. 1 Block diagram of temperature measurement apparatus.
3. Results and discussion

Fig. 2 shows the hot spot pattern on a typical filament observed by current pulsing technique. About 40 lamps were examined to obtain the relation between initial hot spot intensity and filament life. The results showed that only about 10% filaments failed at the initially hottest spot and the failure position of rest filaments were not subject to the influence of the hottest spot. This means that one cannot always relate the hottest spot, found by current pulse technique at the beginning of life, to the condition by which the filament fails.

![Fig. 2 Hot spot pattern observed by current pulsing technique.](image)

The reason for this is that the current pulsing technique is not so effective to coil pitch defects as to check the failure by wire diameter defects.

In order to explain this, the filament temperature burned on pulse current was calculated. The temperature of filament \( T(t) \) can be represented by

\[
T(t) = \frac{1}{Vc} \left( \int_0^t \frac{4I(t) \rho(t)}{\pi D^2} dt - \int_0^t AT^c(t) dt \right)
\]

where

- \( V \) = the volume of wire
- \( C_v \) = specific heat of tungsten
- \( I(t) \) = electric current
- \( D \) = wire diameter
- \( \rho(t) \) = electrical resistivity

The first term is Joule's heat, the second is radiation power and the third is conduction-convection power. The value of \( A \) will change when wire diameter and coil pitch parameter change. To calculate \( T(t) \) it was assumed that radiation power was proportion to \( T^4 \) and \( W_{\text{def}} \) was neglected for simplicity, and experimental value of \( I(t) \) was used. The value of \( A \) was estimated from Vukcevich's equation discribed in Baker's paper\(^5\). Fig. 3 shows the result of calculation. The temperature of wire portion which has 10% decrease in diameter shows a rapid rate of temperature increase, and in the case of a 1% decrease in diameter the temperature rises about 100\(^\circ\)C above undecected portion. However, the temperature of defect portion which has 30% decrease in coil pitch rises scarcely. Therefore, the most of the hot spots which are observed by current pulsing technique at the beginning of life are caused by diameter defects.

On the other hand, under steady state burning, the temperature of the portion of coil pitch defect is higher than the rest part by the effect of mutual heating. In order to investigate the effect of coil pitch defect, temperature distribution along the coils of 30 lamps were examined by steady current method. The stationary temperature distributions along a typical coil are shown in Fig. 4. Fig. 4(c) shows the temperature profile at the life end and temperature decrease resulted from collapse of the primary turn. This collapse of the primary turn was often observed near the life end and this decreased the correlation of the initially highest temperature portion and burnout position. The correlation of these was about 50%, but that of the highest temperature portion and first collapse position was as high as 90%.

Since the cooling effect of the filament end and anchor wire are greater than the case of pulse current burning, the defect part is not so clear, but, in most cases, the irregularities of temperature distribution were observed as shown in Fig. 4. Several coils which observed large irregularities were removed from lamps and examined the coil pitch by scanning electron microscope. The coil pitch deviations up to 15% with respect to the average coil pitch were observed in both primary and secondary coil pitch.

To investigate the causes of pitch defect, the temperature profiles of non-anchored filaments in flashing process were measured. Some examples

![Fig. 3 Temperature-time dependence of defect portion of filament burned on pulse current.](image)

![Fig. 4 Temperature distribution along a coil burned on steady current.](image)
of profile at various temperature are shown in Fig. 5. The pattern (a) shows the temperature distribution burning at 1520 K (average temperature of filament). The temperature difference of right and left part of coil can be seen, but irregularity of temperature is not clear. As temperature rises near a second recrystallization temperature of tungsten (≈2100 K), fine irregularities appear (b). After recrystallization the profile scarcely changed during burning time of 10% of average life. Irregularities appearing near the recrystallization temperature may be due to variation of recrystallization processes. As shown in Fig. 6, second recrystallization occurs at random at its temperature. In Fig. 6, the bright parts are secondly recrystallized grain. In usual, filament wire is doped tungsten and the doped material rises the recrystallization temperature. The inner stress due to coiling processes is removed out before the coil temperature rises up to recrystallization temperature, but in doped tungsten, because of irregularity of doped material concentration the case in which the stress is not removed out uniformly may be occur. In this case, coil pitch becomes not uniform.

The conclusions of this investigation are:

(1) Pitch defect is the main cause of failure in double coiled filament.

(2) Considerable pitch irregularity occurs near the recrystallization temperature.

(3) The hot spots observed by current pulse burning are due to diameter defects.

Reference

(2) P. Korrel and H.C. Plaut: Zeitschr. f. technik. Physik 11 (1930) 515

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