Ir-coated dispenser cathodes for CRTs

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Abstract

Strong demand exists for the development of high-current-density and long-life cathodes for use in cathode ray tubes (CRTs). In response to this demand, the authors have developed and implemented the mass production of two types of Ir-coated 411 type dispenser cathodes having a heater power of 1.31 W and 0.76 W, respectively. These cathodes were designed by computer simulation, and have a structure that allows them to be assembled in electron guns configured for conventional oxide cathodes. The following three types of life tests were carried out in order to confirm the reliability of the cathodes: (1) To investigate temperature changes during the life of the cathodes, a life test of approximately 40,000 h was conducted. The resultant temperature change was small, confirming that the reliability of the cathodes is satisfactory. (2) To investigate emission life, a 32,000 h life test was conducted. The stability of the emission current was thereby confirmed. (3) To investigate heater life, 39,000 h life tests were conducted at several heater temperature levels with a voltage of 300 V applied between the heater and the cathode. From the results of these tests, the minimum life of the heater is estimated to be 80,000 h. The results obtained in the above tests confirm that these cathodes possess good reliability.

Key words: Dispenser cathode, Impregnated cathode, Cathode, Cathode ray tube, Life

1. Introduction

A recent trend in cathode ray tubes (CRTs) is greater brightness, higher definition, and higher reliability, as seen in such fields as color display tubes (CDTs) and high-definition television (HDTV). High current density and long life are therefore required, and long heater life is also an important issue.

To meet these demands, we have developed two types of Ir-coated 411 type dispenser cathode for CRTs, and realized their practical application. The heater power of these cathodes is 1.31 W and 0.76 W, respectively [1]. This paper describes the design, initial and life characteristics, and life estimation of these cathodes.

2. Cathode structures

Figs. 1 (a) and (b) show the structures of the cathodes and heaters. The structure of the cathode is compatible with that of the conventional oxide cathode assembled in Toshiba color picture tubes (CPTs) and CDTs. Therefore, a cathode holder identical to that part in the conventional oxide cathode is used. Moreover, the structure of the cathode has a design that allows automated mass production. The emitter consisting of BaO, CaO, and Al2O3 in a molar ratio of 4:1:1 is impregnated in a cathode disc made of porous tungsten having 17% porosity. The cathode surface is coated with an Ir layer of 150 nm in thickness.

Fig. 1 (a) shows the cathode type with a heater power of 1.31 W. The heater rating is 6.3 V and 0.21 A. The diameter of the cathode disc is 1.1 mm. The cathode cup, cathode sleeve, and strap are made of tantalum. For the heater, 3%Re-W alloy wire is used to form a heater of the coiled double helical type. On its surface, an originally developed alumina powder layer forms the first layer, and a layer comprising a mixture of alumina powder and tungsten powder forms the second layer.

Fig. 1 (b) shows the cathode type with a heater power of 0.76 W. The heater rating is 6.3 V, 0.12 A. The diameter of cathode disc is again 1.1 mm. This cathode differs from the 1.31 W type in terms of the following points: (1) The strap and cathode sleeve are downsized. (2) A reflector is attached in order to reduce radiation loss. (3) A blackened layer consisting of tungsten powder and alumina powder is coated on the inside of the sleeve so that it effectively absorbs heat from the heater.
3. Cathode design

a. Thermal design

We created a program for calculating the radiation loss and conduction loss from each part of the cathode. The cathode sleeve was divided into 46 elements, and each element was made into a model of heat reflection from the first grid (G1) or the inner wall of the cathode holder. The cathode strap was divided into 10 elements, and made into a model of conduction while each element surface was subjected to radiation.

Table 1 shows the results of calculating the heat loss of the 1.31 W type cathode using this program. From the results obtained, it was found that the major components of heat loss are (1) radiation loss (36.6%) from the cathode sleeve, (2) conduction loss (24.2%) from the cathode strap, and (3) radiation loss (20.9%) from cathode sleeve open section.

For the design of the 0.76 W type cathode, studies were carried out in order to reduce the major components of heat loss of the 1.31 W type cathode. The design consequently featured a reduction in the diameter of the cathode sleeve, the attachment of a reflector, and a reduction in the cross-sectional area of the cathode strap. Figs. 2 (a) to (d) show the results obtained from these studies using the calculation program. Figure (a) shows the relationship between the cathode sleeve diameter and heat loss, (b) shows that between the reflector length and heat loss, (c) shows that between the reflector diameter and heat loss, and (d) shows that between the strap shape and heat loss.

The design of the 0.76 W type cathode was determined reflecting the above study results and the structural design results described next. Table 2 shows the changes in design and the results of heat loss calculations.

b. Structural design

In order to minimize conduction loss from the strap, the cross-sectional area of the strap of the 0.76 W type cathode was reduced by 40% compared to that of the 1.31 W type. Structural analyses were carried out to investigate the effects of this design change on the cathode characteristics. The NASTRAN (NASA Structural Analysis) finite element method was used for these analyses.

Thermal displacement analysis revealed that when the heater was activated, the cathode disc surface was 22 μm closer to the first grid (G1) side. This degree of deformation is about the same that of the 1.31 W type cathode.

Table 1 Calculated result of heat loss of 1.31 W type cathode

<table>
<thead>
<tr>
<th>Component of heat loss</th>
<th>Heat loss (W)</th>
<th>Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation loss from cathode disc</td>
<td>0.028</td>
<td>2.0</td>
</tr>
<tr>
<td>Radiation loss from cathode sleeve</td>
<td>0.509</td>
<td>36.6</td>
</tr>
<tr>
<td>Radiation loss from cathode strap (×3)</td>
<td>0.090</td>
<td>6.4</td>
</tr>
<tr>
<td>Radiation loss from cathode sleeve open section (reactive power)</td>
<td>0.293</td>
<td>20.9</td>
</tr>
<tr>
<td>Radiation loss from heater exposed section (×2)</td>
<td>0.083</td>
<td>5.9</td>
</tr>
<tr>
<td>Conduction loss from cathode strap (×3)</td>
<td>0.339</td>
<td>24.2</td>
</tr>
<tr>
<td>Conduction loss from heater legs (×2)</td>
<td>0.054</td>
<td>3.9</td>
</tr>
<tr>
<td>Total loss (calculated value)</td>
<td>1.40</td>
<td>100</td>
</tr>
<tr>
<td>Total loss (measured value)</td>
<td>1.31</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Calculated results of heat loss of 0.76 W type cathode

<table>
<thead>
<tr>
<th>Component of heat loss and principal changes compared to 1.31 W type</th>
<th>Heat loss (W)</th>
<th>Ratio (%)</th>
<th>Reduction effect (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation loss from cathode disc</td>
<td>0.028</td>
<td>3.3</td>
<td>0</td>
</tr>
<tr>
<td>Radiation loss from cathode sleeve: (1) Sleeve dia. reduced by 20%, (2) Reflector of 1.6 dia. mm and 2.8 mm length attached</td>
<td>0.304</td>
<td>35.7</td>
<td>0.205</td>
</tr>
<tr>
<td>Radiation loss from cathode strap (×3): Cross-sectional area of strap reduced by 40%</td>
<td>0.070</td>
<td>8.2</td>
<td>0.020</td>
</tr>
<tr>
<td>Radiation loss (reactive power) from cathode sleeve open section: (1) Sleeve dia. minimized, (2) Heater temp. reduced by blackening inner surface of sleeve</td>
<td>0.142</td>
<td>16.7</td>
<td>0.151</td>
</tr>
<tr>
<td>Radiation loss from heater exposed sections (×2): Heater leg dia. minimized</td>
<td>0.081</td>
<td>9.5</td>
<td>0.002</td>
</tr>
<tr>
<td>Radiation loss from cathode strap (×3): Surface area of strap reduced by 11%</td>
<td>0.197</td>
<td>23.1</td>
<td>0.142</td>
</tr>
<tr>
<td>Conduction loss from heater legs (×2): Heater wire dia. minimized</td>
<td>0.030</td>
<td>3.5</td>
<td>0.024</td>
</tr>
<tr>
<td>Total loss (calculated value)</td>
<td>0.85</td>
<td>100</td>
<td>0.54</td>
</tr>
<tr>
<td>Total loss (measured value)</td>
<td>0.76</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Thermal stress analysis showed that the thermal stress of the bent section of the strap was 8 N/mm². This value is sufficiently small for a high-temperature tensile strength of 150 N/mm² of the Ta strap material at this temperature (1200 K). The safety of this design point was therefore confirmed.

In vibration analysis, the first natural frequency was 3.3 kHz, while the second and third natural frequencies were 15.6 kHz and 15.7 kHz, respectively. The strap shape used for these calculations was 0.3 mm in width and 0.03 mm in thickness, and the strap material was Ta. In this connection, the calculation results when the strap was changed to Re-W wire with a diameter of 30 μm showed that the first natural frequency decreased to 0.3 kHz. Although the use of fine wire for the strap is advantageous in terms of reducing heat loss, it was not adopted because the decrease in natural frequency causes disturbance of the television picture image due to speaker vibration.

4. Initial characteristics

a. Temperature-rise characteristics of cathodes

The temperature-rise characteristics were measured by radiation thermometer. Fig. 3 shows the results. The time required for the cathode temperature to reach 850 K (the temperature corresponding to the picture emergence time, described below) was 5.5 s for the 1.31 W type and 4.6 s for the 0.76 W type, confirming the quick-performance design of both cathodes.

b. Tube initial characteristics

The 1.31 W type and 0.76 W type cathodes were assembled in 41 cm (17-inch) CDTs, and their initial characteristics were evaluated. The 0.76 W type was found to be about 1 s faster in terms of picture emergence time (the time until the picture begins to appear after switching on) as well as the time until the picture is recognizable after switching on. Both cathodes exhibited the same gamma characteristics. This is because both cathodes were set at the same cathode temperature: 1300 K. Moreover, although the cross-sectional area of the strap of the 0.76 W type was reduced by 40% compared to that of the 1.31 W type, the 0.76 W type showed good thermal drift (fluctuation of cathode current at the time of picture emergence) and shock white balance characteristics comparable to those of the 1.31 W type.

5. Life tests

a. Changes in cathode temperature during life tests

Both types of cathodes were assembled in electron guns in which the cathode temperature can be measured, and life tests were conducted at heater voltage \( E_f = 6.3 \) V (rated) and \( E_f = 7.0 \) V (accelerated). Fig. 4 shows the variations in cathode temperature up to the maximum time of 40,000 h. As can be seen in the figure, the variations in cathode temperature are very small for both types of cathodes, thus confirming that satisfactory reliability is obtained.

![Fig. 2 Calculated results of heat loss vs. cathode design. (a) Heat loss vs. sleeve diameter, (b) Heat loss vs. reflector length, (c) Heat loss vs. reflector diameter, (d) Heat loss vs. strap shape, ERST: Radiation loss from a strap, ECST: Conduction loss from a strap.](image-url)
135, and the maximum test time was 32,000 h.

The average emission current residual ratio for 1.31 W type cathodes was 106.0% at 32,000 h in the case of $E_f = 7.0$ V, and 101.4% at 30,000 h in the case of $E_f = 6.3$ V.

The average emission current residual ratio for 0.76 W type cathodes was 96.1% at 18,000 h in the case of $E_f = 7.0$ V, and 102.8% at 20,000 h in the case of $E_f = 6.3$ V. These results indicate that no deterioration in emissions occurred in either the 1.31 W type or 0.76 W type, and that they have satisfactory emission performance.

![Graph showing cathode temperature](image)

**Fig. 3** Time dependence of cathode temperature of 1.31 W type and 0.76 W type cathodes.

![Graph showing variations in cathode temperature](image)

**Fig. 4** Variations in cathode temperature during life of 1.31 W type and 0.76 W type cathodes.

c. **Heater life tests**

Life tests are being conducted combining various heater temperatures ranging from 1490 K to 1670 K [2]. The cathode and heater used are the 1.31 W type cathode and heater. The heater temperature at its rated operating condition is 1490 K. In this test, a direct potential (Chk) of 500 V is forcibly applied between the heater and the cathode while maintaining the negative charge of the heater side. The total number of experimental tubes is 81. The present time of the life test is 39,000 hours. The results obtained so far are plotted in Fig. 5. The samples that have broken so far during the test period are indicated by ( ), while those that have not yet broken are indicated by ( ). The solid line in Fig. 5 shows the relationship between the minimum life and the heater temperature, while the straight line at the lower side in the figure shows the results obtained by Metson et al. in tests using heaters for receiving tubes [3]. As can be seen from these results, the gradients of both lines are almost identical.

When the minimum life under the rated operating conditions (heater temperature of 1490 K) is estimated from these results, the figure of 80,000 hours is obtained.

![Graph showing relationship between heater life and temperature](image)

**Fig. 5** Relationship between heater life and temperature. The samples that have broken during the life test are indicated by ( ), while those that have not yet broken are indicated by ( ). Figures above marks indicate the number of not yet broken samples.

6. **Conclusion**

We have developed and realized the practical application of Ir-coated dispenser cathodes for CRTs to provide high current density and long life, which operate at the same heater power as oxide cathodes. The thermal design and structural design of the cathodes was optimized by computer simulation. The satisfactory reliability of these cathodes has been confirmed by life tests conducted for approximately 40,000 h. At the present time, these cathodes are being fabricated by automated mass production and incorporated in Toshiba CRTs.

References