Analysis of Arc Tube Properties by Degradation in Ceramic Metal Halide Lamp

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Abstract - To clarify the relations of optical properties to the main factors responsible for the loss and damage of luminous efficacy, a 20 min turn-on/turn-off test for 2,000 h for a ceramic metal halide lamp is conducted. The corrosion rates of the arc tube wall and electrode are estimated based on thermal stress. Wall blackening is attributed to the tungsten being transported from the hot electrode tips to the relatively cold arc tube wall. Furthermore, the grain boundaries of the arc tube are changed by the degradation. Distortion of the electrode is observed, and the ignition and the driving voltage of the load both increase. Finally, the color rendering index and the color coordinates are changed after the degradation. The luminous flux and the intensity of the luminous distribution are decreased significantly.

Keywords: Ceramic metal halide, Degradation, Arc tube, Wall blackening, Discharge

1. Introduction

A ceramic metal halide lamp usually contains mercury as the buffer gas and rare earth additives that radiate very efficiently in the visible spectrum. While applying an ignition voltage of 4 kV to the arc-tube, thermal and optical energy is generated by strong plasma convection. Thermal energy and optical energy are emitted to the outside through a ceramic arc tube made of Al_2O_3 .

However, plasma convection in an arc tube at high pressure and temperature results in a loss of tungsten, iodine composite, and rare earth elements, as well as the corrosion of the arc tube by chemical recombination [1]-[3].

Furthermore, because of the corrosion of the electrode and the arc tube, the initial arc shape changes accordingly with the change in the magnetic properties. Ultimately, this phenomenon leads to the damage of the discharge lamp and to inferior performance.

In this study, to clarify the relation of optical properties with the main factors responsible for the loss and damage of luminous efficacy, we conduct a 20 min turn-on/turn-off test for 2,000 h on a ceramic metal halide lamp.

2. Theory and Experimental Setup

2.1 Discharge Theory of Ceramic Metal Halide Lamp

A ceramic metal halide lamp was used for replacing the ceramic materials from quartz in an arc tube. The structure

of the discharge is shown in Fig. 1. When high ignition voltage is applied through two electrodes, the initial discharge process of the ceramic metal halide lamp involves a glow discharge for a few microseconds (μs) after the break-over of the buffer gas.

As the temperature of the arc tube gradually increases, the melting and evaporation of the metal halide begins and moves to the center of the arc tube. The metal and halogen atoms then become separated. The arc is formed from the emitted light caused by the collision between the metal elements and the electrons [6].

Fig. 2 shows the V-I transition curve of the ceramic metal halide lamp.

The power of the lamp increases with an increase in voltage in the glow-to-arc transition state, in which the metal and the halogen elements are recombined at a cold spot. Thereafter, the lamp enters thermal equilibrium state from arc discharge state, and the current becomes constant. When the on-off test is carried out continuously, high current and voltage are required for ignition, and the stress is accelerated by a change in the inner pressure.

Fig. 1. Discharge phenomenon inside cylindrical ceramic arc tube.

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Fig. 2. V-I curve according to discharge process in ceramic metal halide lamp.

2.2 Theory of Wall Blackening Phenomenon

Fig. 3 illustrates the wall blackening phenomenon in the arc tube. Wall blackening is caused by a thin layer of electrode material being deposited on the inner wall of the discharge tube over its lifetime. The electrode is designed for nominal lamp power; thus, deviations in lamp power caused by under-voltage or over-voltage of the main power supply cause this blackening process [4].

The discharge and intensive ion bombardment caused by the process severely overheat the electrodes; therefore, tungsten and other electrode materials become splattered on the internal bulb walls of the arc chamber, accelerating the wall blackening phenomenon.

Fig. 3. Illustration the theory of wall blackening.

2.3 Experimental Method and Equipment

Using a 20 min on/off test, a ceramic metal halide lamp was evaluated for 2,000 h under the condition of accelerated aging based on the RSC0085 High Intensity Discharge Lamp (HID) reliability evaluation criterion, as shown in Fig. 4. Twenty minutes was set as the on/off time, by considering the stable state time and restart-discharge condition. Degradation time can be estimated at approximately 5,000 h using the relation between the rate of flickering and the lifetime of the lamp. A magnetic ballast of 150 W was used at an ambient temperature of 25 °C [7].

Furthermore, an integrating sphere (PMS-50, EVERFINE Corp.) was used for estimating the optical

Fig. 4. Experimental setup.

properties of the sample. An X-ray non-destructive system (SMX-225CT Special, Shimadzu Corp.) and an FE-SEM (S-4800, Hitachi Corp.) were used for analyzing the structural characteristics.

3. Results and Discussion

3.1 Wall Blackening Phenomenon in Arc Tube and Degradation in Electrode and Surface

Fig. 5 shows the blackening of the arc tube and the deterioration of the surface of the electrode caused by the accelerated degradation test.

In the arc tube, wall blackening is caused by the transportation of tungsten from the hot electrode tips to the relatively cold arc tube wall. The deteriorating translucence is further attributed to the formation of a $3\text{Dy}_2\text{O}_3\text{-}5\text{Al}_2\text{O}_3$ garnet, the thermal etching of alumina, and the abnormal growth of the alumina grains [3].

Fig. 6 shows the growth of the electrode degradation. The tungsten shifted to the arc tube wall from the electrode, as shown in Tables 1 and 2. As shown in Equation (1), tungsten combined with oxygen and iodine at a high temperature, and was deposited as WO_2I_2 near the wall. In this situation, regeneration does not occur in the system when regeneration and deposition are repeated, causing the wall blackening and degradation of the electrode [3].

Fig. 5. Wall blackening phenomena in arc tube.

Fig. 6. FE-SEM of electrode changed by degradation.

Table 1. Surface components in electrode

Initial surface components of electrode [%]			Surface components of electrode after 2,000 h [%]		
Element	Weight	Atomic	Element	Weight	Atomic
C	8.22	39.88	C	9.64	29.33
O	9.14	33.27	O	20.05	45.83
I	6.41	2.94	Na	6.97	11.09
W	68.59	21.73	I	12.96	3.73
Tl	7.64	2.18	W	50.38	10.02
Total	100.00		Total	100.00	

Table 2. Surface components in arc tube

Initial surface components of arc tube [%]			Surface components of arc tube after 2,000 h [%]		
Element	Molecular Weight	Atomic Weigh	Element	Molecular Weight	Atomic Weigh
C	4.68	7.61	C	7.52	17.15
O	48.58	59.29	O	29.75	50.96
Al	45.32	32.80	Na	1.85	2.20
Zr	1.42	0.30	Al	23.47	23.84
			I	4.08	0.88
			W	33.33	4.97
Total	100.00		Total	100.00	

Fig. 7 shows the change of grain boundaries in the arc tube because of the degradation. Transmittance is decreased by the wall blackening and the scattering of residual porosity. Moreover, at the one-week mark, cracks appear on arc tube wall from thermal stress corrosion in some samples [5].

Fig. 8 shows the distortion of the electrode in the arc tube after 2,000 h. Rare earth elements, which are additives in the arc tube, accumulate through the chemical reaction between the electrode and the tube, as shown in Equations (2) and (3).

The thermal expansion coefficient of the electrode changes from that of the bond material because of combination with the additive. As a result, the electrode becomes distorted, and the ignition and driving voltage of load increase from 82.2 to 101 V. These changes of voltage affect the arc formation.

Fig. 7. FE-SEM of arc tube changed by degradation.

Fig. 8. Wall blackening phenomenon in the arc tube.

RE: Rare earth iodides

3.2 Change in Optical Properties of Arc Tube

Metal halide compounds and rare earth metals are added to the ceramic metal halide lamp in order to improve the efficiency and the color rendering index. The composition of additives can be identified by using spectrum analysis, as shown in Fig. 9. In the tested lamp, the metal halide pill consists of the NaI-TlI-DyI₃-CeI₃ compound. The Dy and Ce contents were reduced with a spectrum line having a wavelength of 400-450 nm, depending upon the degradation.

Fig. 10 shows the change in the color rendering index and the color coordinates after degradation. The color rendering index of the lamp was slightly lowered, from 88.7 to 87.8, and R9 was reduced distinctively. Therefore, the color temperature also changed from 4,200 to 3,143 K.

The luminous flux changed from the initial value of 9,006.5 to 5,993.9 lm after 2,000 h because of the internal loss and structural changes (i.e., wall blackening). Fur-

Fig. 9. Spectra of estimated change in additives in arc tube.

(a) Color rendering index

(b) Color coordinates

Fig. 10. Change in color rendering index and color coordinates. **Fig. 11.** Change of luminous distribution.

thermore, the intensity of the luminous distribution decreased, as shown in Fig. 11.

5. Conclusion

In this study, in order to clarify the relation of optical properties with the main factors responsible for the loss and damage of luminous efficacy, a 20 min turn-on/turn-off test was conducted for 2,000 h on a ceramic metal halide lamp. As a result, the following conclusions were drawn:

1. The corrosion of the arc tube wall and electrode is attributed to the thermal stress and wall blackening be-

- cause of the transportation of tungsten from the hot electrode tips to the relatively cold arc tube wall.
2. Grain boundaries of the arc tube are changed by degradation. Moreover, the transmittance is decreased by the wall blackening and scattering of the residual porosity
3. The thermal expansion coefficient of the electrode changes from that of the bond material because it combines with the additive. As a result, the electrode becomes distorted, and the ignition and driving voltages of the load increase.
4. Finally, the color rendering index and the color coordinates are changed after the luminous flux becomes degraded, and the intensity of the luminous distribution decreases significantly.

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