Investigation of Turn-off Condition for Reliable Operation of Mercury Vapor Lamp

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Abstract
The distributions of mercury (Hg) in the bulb of a mercury vapor lamp are significantly affected by its turn-off conditions. Most of mercury should be attached to the electrodes before ignition by a proper turn-off condition. In the present study, the effect of the transient profiles of lamp cooling after turn-off on the distribution of Hg was investigated.

1. Introduction

The performance of projection systems (rear projection TVs, projectors and etc.) are intimately associated with that of light sources. In general, other than their optical performances such as output lumen, contrast and so on, the lifetime is an issue of vital concern to consumers. The lifetime of projection systems is likely to be in excess of 10,000 hrs, unless that of lamps is considered. Therefore, when a projection system is designed, the reliability of lamps is an unavoidable core topic for designers at all times.

Most of projection systems use arc lamps, which are well-known as high-intensity discharge (HID) lamps. Among them, a mercury vapor lamp is the subject of present investigation, which is characterized by the very short arc gap providing a narrow beam bundle to micro display panels.

At the normal operation of lamps, the temperature of bulb should be kept to be around 900-1,000 ^oC and that of electrodes below ~400 ^oC. These conditions are described in the product specification provided by each lamp manufacturer. They are very important restrictions to guarantee the announced product lifetime. Also the turn-off conditions of mercury vapor lamps can severely affect their lifetime, extensively reliability. Hence, they have to be checked in the early design stage.

In the present study, the lamp turn-off conditions, which are easy to overlook, were dealt with. The effects of the transient lamp-cooling profile after turning off lamps and the temperature of front foil at turn-off on the distributions of Hg in the envelope of lamp bulb were discussed and investigated in view of reliability. Fig. 1 shows the x-ray picture of a lamp bulb after use, in which Hg is attached to the lamp envelope so that darkening and clouding [1] could occur at re-ignition.

The detailed description of experiments and their results are given in the following sections.

2. Experiments

Not only the operating states of mercury vapor lamps, but also their turn-off stages are important for improvement of their performance (lumen output, lifetime and so on). Especially, the turn-off condition of lamps is directly connected with the damage of their bulbs. Therefore, it should be investigated to elevate the reliability of the systems to use the lamps. Especially, at the design stage, the operating and turn-off conditions of mercury vapor lamps for more stable and reliable operation should be carefully examined. Eventually it is expected to raise the reliability of projection systems as well as lamps.

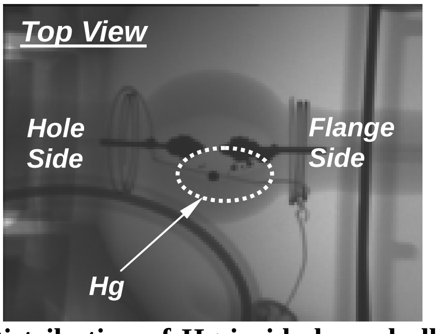


Fig. 1. Distribution of Hg inside lamp bulb; Hg is attached to the lamp envelope.

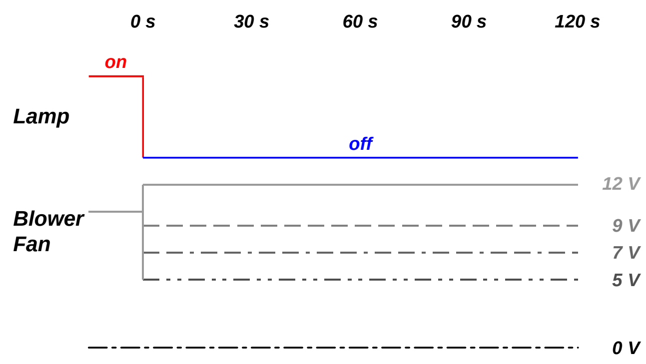


Fig. 2. Voltage profiles of a blower fan to cool lamp bulb and front foil after turn-off.

When the lamp turns off, the factors to exert adverse effects on its reliability are the temperature(s) of front foil or electrodes, and the post cooling process to protect the projection systems from high temperature environment before re-ignition.

The former causes the removal and oxidization of material from the front foil or electrodes [2]. The electrodes play a couple of important roles. The first is the formation of arc, and the second provides the easy Hg attachment to electrodes for the re-ignition after the lamp turn-off. The reason why the other can be achieved is that the electrodes are commonly at the lowest temperature in the lamp bulb. Generally, the phase of mercury is changed from liquid to gas or from gas to liquid at ~300 ^{o}C. As the temperature of front foil becomes lower to a certain level not affecting the generation of light, the oxidation of Mo lessens and the liquefaction of Hg is easily taken place on the electrodes.

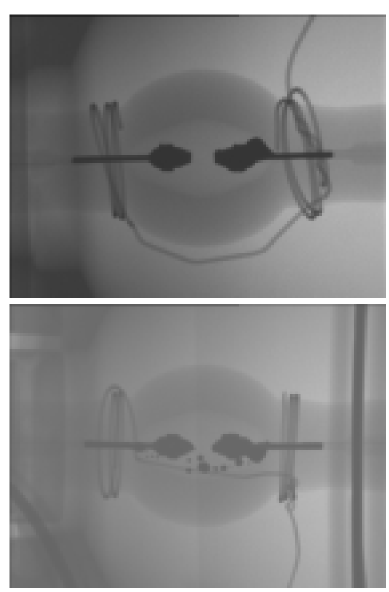
The latter means controlling the transient temperature variations of both lamp bulb and front foil (or electrodes), in order not to occur attaching Hg to the envelope after turn-off. The attachment of Hg results from the abrupt temperature drop of lamp bulb.

In the present paper, the essential points for the reliable lamp operation were suggested from the following experiments. At first, the effect of the temperature of front foil, T_{ff} on the distribution of Hg in its bulb was examined with the same turn-off cooling profile. Two T_{ff}s were selected such as 310 and 360 ^{o}C. In the experiment for the second issue, the connection between the blower fan voltage (which was proportional to its volume flow rate) and the Hg attachment was ascertained. It gave the clear answer of how the temporal gradient of the lamp bulb and front foil temperatures, $\partial T_{bulb}/\partial t$ and $\partial T_{ff}/\partial t$ affected the liquefaction of Hg after the lamp turn-off. From the lamp turn-off, the fan voltages chosen as an experimental parameter were depicted in Fig. 2.

3. Results and discussion

The mercury vapor lamps applied to lots of projection TVs and the projectors are switched on/off thousands of times. In order to solve the problems (darkening or clouding of the envelope of bulb) occurred at the igniting and turning-off states, untiring engineering efforts are needed at the early design stage. In the present study, the Hg distributions of an AC 210 W Hg lamp employed by a projector were investigated in accordance with the temperature of lamp front foil at the moment of turn-off and the cooling profiles after the lamp turn-off.

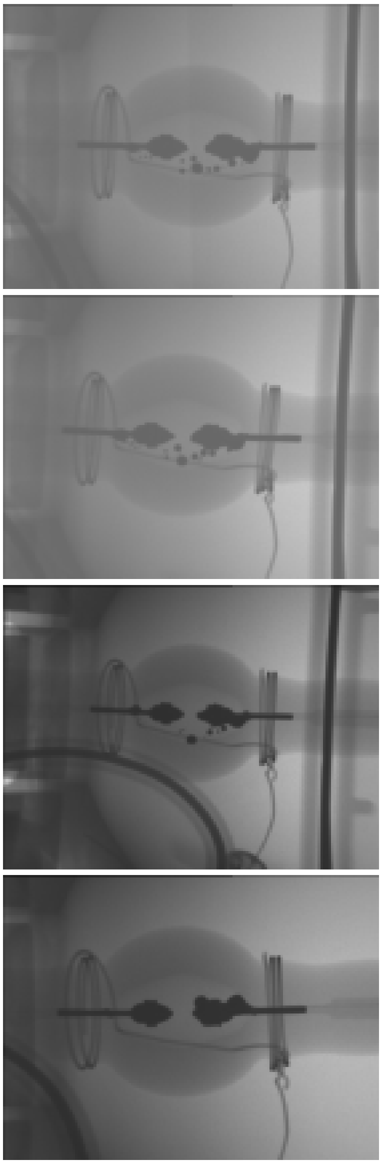
The operating temperature of front foil, T_{ff} (< ~400 ^{o}C), has influence on a post-operating state of mercury vapor lamps, such as the distribution of Hg. After a lamp was operated at T_{ff} = 310 and 360 ^{o}C, the distributions of Hg inside the lamp bulb were shown in Fig. 3. It shows the remarkable difference. At T_{ff} = 310 ^{o}C, most of Hg was distributed on the electrodes, while at T_{ff} = 360 ^{o}C, the considerable amount of Hg was attached to the lamp envelope. When the front foil of lamp is set at hot environment and cooled down, the distribution of Hg is determined by the location of the lowest temperature region. Consequently, as T_{ff} becomes lower, more amount of Hg can be attached to the electrodes connected to the front foil.



(a) $T_{ff@turn\text{-}off}$ = 310 ^{o}C

(b) $T_{ff@turn\text{-}off}$ = 360 ^{o}C

Fig. 3. Distributions of Hg inside lamp bulb after use according to T_{ff}s just at the lamp turn-off.



(a) V_{blower} = 12 V

(b) V_{blower} = 9 V

(c) V_{blower} = 7 V

(d) V_{blower} = 5 V

Fig. 4. Distributions of Hg inside lamp bulb after use according to voltages of a lamp cooling blower fan.

Within a temperature range sustaining the light-emitting cycle of a mercury vapor lamp, the operating temperature of front foil should be kept to be as low as possible for the reliable operation of lamps. Considering the present experimental results and the temperature of Hg liquefaction, the most favorable operating condition for T_{ff} is around 300 ^{o}C.

Generally, in order to reduce the time for system cooling at the turn-off stage, all of the cooling fans inside projection systems are operated at their maximum voltages. In this case, the mercury, which usually begins to be liquefied around 300 ^{o}C, is distributed along the envelope of lamp bulb by the abrupt bulb cooling as shown in Fig. 1 and Fig. 4(a). It also results in that the initial electric discharge for the lamp ignition hits the mercury attached to the envelope of the bulb, so the darkening could occurred.

The distributions of Hg in accordance with the volume flow rates (or voltages of lamp cooling blower fan) were illustrated in Fig. 4 and placed in a column. As the blower voltage turned down, the amount of Hg attached to the lamp envelope was reduced. The reason is that the temperature of electrodes is kept even lower than that of the bulb in a longer time. In the normal operation, the temperature of electrodes is not over 400 ^{o}C, while that of the bulb is around 1000 ^{o}C. Hence, when the gradual cooling profile, $\partial T/\partial t$ is applied, most of Hg is attached to the electrodes, not the envelope as shown in Fig. 4(d). Consequently, a simple modification of the cooling profile after the lamp turn-off can considerably diminish the damage of the bulb and solve most of the problems except the removal of material from the electrodes.

However, it cannot always be acceptable for usual lamp users, since it takes much time to restart a projection system. Therefore, when a system to use mercury vapor lamps is newly developed, a tuning process between $\partial T/\partial t$ and the consuming time for turning off a system is inevitable.

4. Conclusions

In order to keep the projection systems in a stable operation, the selection and control of light sources are significant. The present paper introduced some turn-off conditions for improving the reliability of mercury vapor lamps. The experimental results reveal that it is favorable for the temperature of front foil to be kept to be around 300 ^{o}C. The reason is that the oxidizing rates of both front foil and electrodes become lower and it is advantageous for Hg attachment to electrodes. When a lamp is cooled after turn-off, the abrupt temperature variation of lamp could cause damage to the lamp igniter.

5. References

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