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Detection of acoustic resonance in metal halide lamps

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Abstract

Investigation of the acoustic resonance in metal halide lamps is essential for engineers designing a high-frequency electronic ballast. This paper proposes a simple method of detecting the acoustic instability by measuring the lamp voltage. The standard deviation in the lamp voltage is used as an index to determine the occurence of acoustic resonance. With this index, the degree of the lamp arc instability can easily be specified. Experiments are carried out on various 70W lamps to inspect the influence of the lamp type, the used hours, and the operating power on the frequency spectra of acoustic resonance.

1 Introduction

The metal halide lamp has become an attractive lighting source because of its compact size, good color rendering, and high luminous efficacy [1]. As all high-intensity discharge lamps, it has a negative incremental resistance, which claims the necessity of a ballast circuitry. Similar to other gas discharge lamps, the lighting performance can be improved when driven by a high-frequency electronic ballast. Though, electronic ballasts are commonly used over fluorescent lamps, the applications of electronic ballasts for metal halide lamps are not so popular. One of the obstacles in electronically ballasting of metal halide lamps is the phenomenon of acoustic resonance [2].

Some elementary understanding and theoretical explainnation of acoustic resonance have been presented [3]. Acoustic resonance is induced by the periodically injected electric power that matches the intrinsic eigenfrequency of the lamp. The lamp's eigenfrequencies might be influenced by the lamp shape, size, the filled gas type and gas pressure, etc. The periodic electric power injected from the high-frequency electronic ballast causes a pressure wave propagating inside the arc tube of the lamp. If the propagating wave has a frequency that matches one of the intrinsic eigenfrequencies of the operating lamp, a standing wave will occur. The resulted standing wave inside the arc tube disturbs the lighting arc flow, therefore, the light output glitters. Moreover, the gas wave will cause fluctuations of pressure inside the lamp tube, which may even cause some permanent damage of the lamp.

There are versatile parameters related to the eigenfrequencies of a lamp, therefore, influencing the occurrence of acoustic resonance, such as the gas type and pressure filled inside, the arc-tube shape and size, the electrode size and distance, ambient temperature, in addition to the electrically driving power frequency and intensity. All these factors make acoustic resonance a difficult problem to be predicted or to be described by analytical expressions.

In order to alleviate or eliminate the phenomenon of acoustic resonance, many approaches of electronic ballasting have been proposed besides modification of the arc vessel geometry, such as operating at a specified frequency, low frequency operation, ultra high frequency operation, frequency modulation, and frequency transition [4,5]. Among them, operation of the lamp at a frequency away from acoustic resonance frequencies appears to be the most efficient and cost-effective. However, this method resorts to recognition of the frequency ranges in which acoustic resonance will not occur. For this purpose, this paper proposes a simple method for detecting the acoustic instability by measuring the lamp voltage instead of observing the lamp arc by human eyes. With the measured index, the degree of lamp arc instability can easily be specified. The detection method is implemented on several types of 70W lamps to inspect the variation of the frequency spectra of acoustic resonances.

2 Phenomena of acoustic resonance

Unstable light output is usually observable when acoustic resonance occurrs. In practice, the occurrence of acoustic resonance can be judged by human eyes. Fig. 1 shows the acoustic resonance occurrence in a 70W lamp driven by an electronic ballast over the frequency range from 20kHz to 80kHz. The degree of darkness denotes the seriousness of acoustic resonance. The frequencies in gray denote the unstable light output, while the deep black bands represent violent acoustic resonance or may even cause the lamp arc to break. On the other hand, pure white areas are free from acoustic resonance. In this illustrative example, it is found that there are several frequency bands without acoustic resonance.

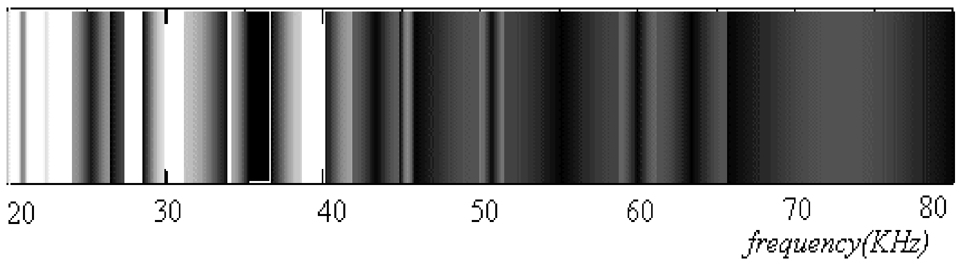

Figure 1: Occurrence of acoustic resonance over different driving frequencies.

It is reasonable to interpret this unstable phenomenon as a result of disturbances in electrical characteristics of the lamp [6, 7]. Fig. 2 shows the waveforms of the lamp voltage and the lamp current with and without acoustic resonance. These waveforms are obtained by the "persistence function" of the oscilloscope. With the "persistence function", several sampled waveforms are displayed on the same screen. By inspecting such waveforms, fluctuations in both voltage and current can be observed. It is found that the occurrence of acoustic resonance is related to the fluctuations of the lamp voltage and current. Besides, the fluctuations in the lamp voltage are dominant over that in the lamp current when the lamp is suffering from the arc instability.

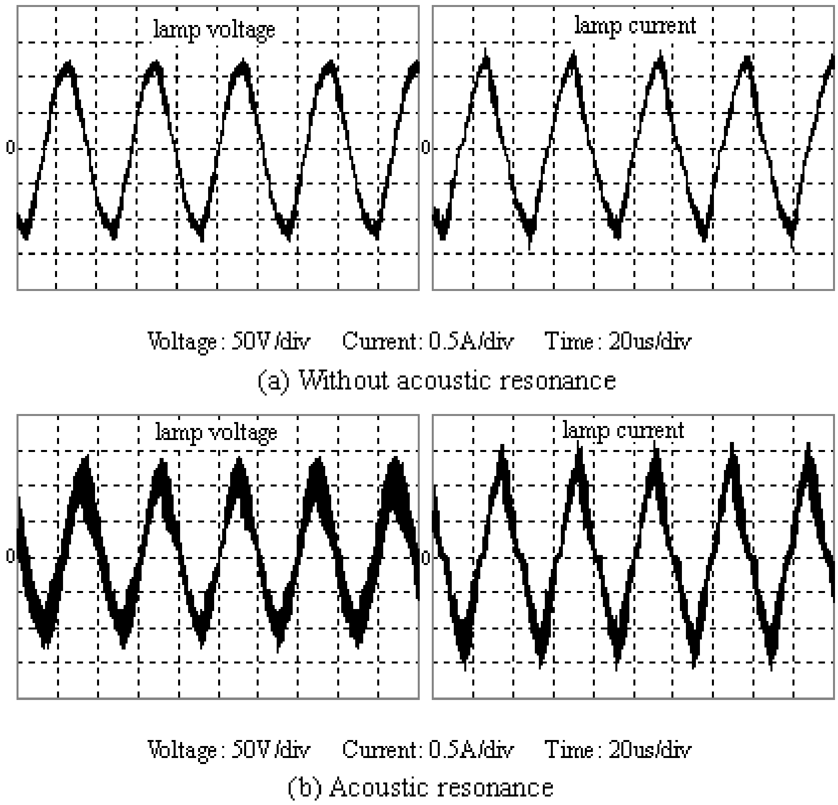

Figure 2: Lamp voltage and current with and without acoustic resonance.

3 Index of acoustic resonance

In order to quantify the extent of fluctuations in the lamp voltage and the lamp current, the standard deviation is introduced. The definition of standard deviation is denoted as:

$$\delta = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2} \tag{1}$$

where n is the number of sampled cycles, X_i is the real-time value for each measured cycle, and $\overline{X}$ is the mean of the n samples of X.

Fig. 3 shows the standard deviations of the lamp voltage and current of a metal halide lamp over the same driving frequency range in logarithmic scale.

The frequency band between the two dashed lines denotes an extinguishing arc; therefore, no arc current flows through and the measured arc voltage is not meaningful. As compared to Fig. 1, it is obvious that the occurrence of acoustic resonance is strongly related to the standard deviation of the lamp voltage, while the standard deviation of the lamp current does not vary remarkably with the occurrence of acoustic resonance. By scrutinizing Figs. 1 and 3, it can be found that the standard deviation of the lamp voltage will be less than 0.3V when the lamp is free from acoustic resonance. Therefore, standard deviation of the lamp voltage can be selected as an index indicating the occurence of acoustic resonance.

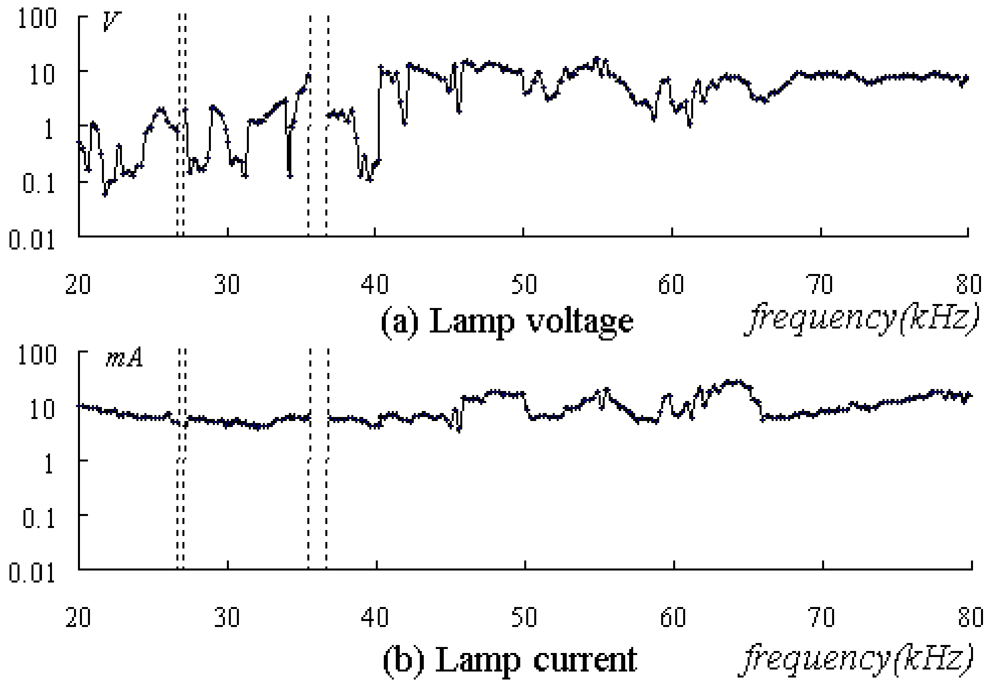

Figure 3: Standard deviations of lamp voltage and current.

4 Experiment results

In order to verify if the standard deviation is an applicable index to judge the occurrence of acoustic resonance, experiments are carried out on several 70W metal halide lamps. Fig. 4 shows the standard deviations of the

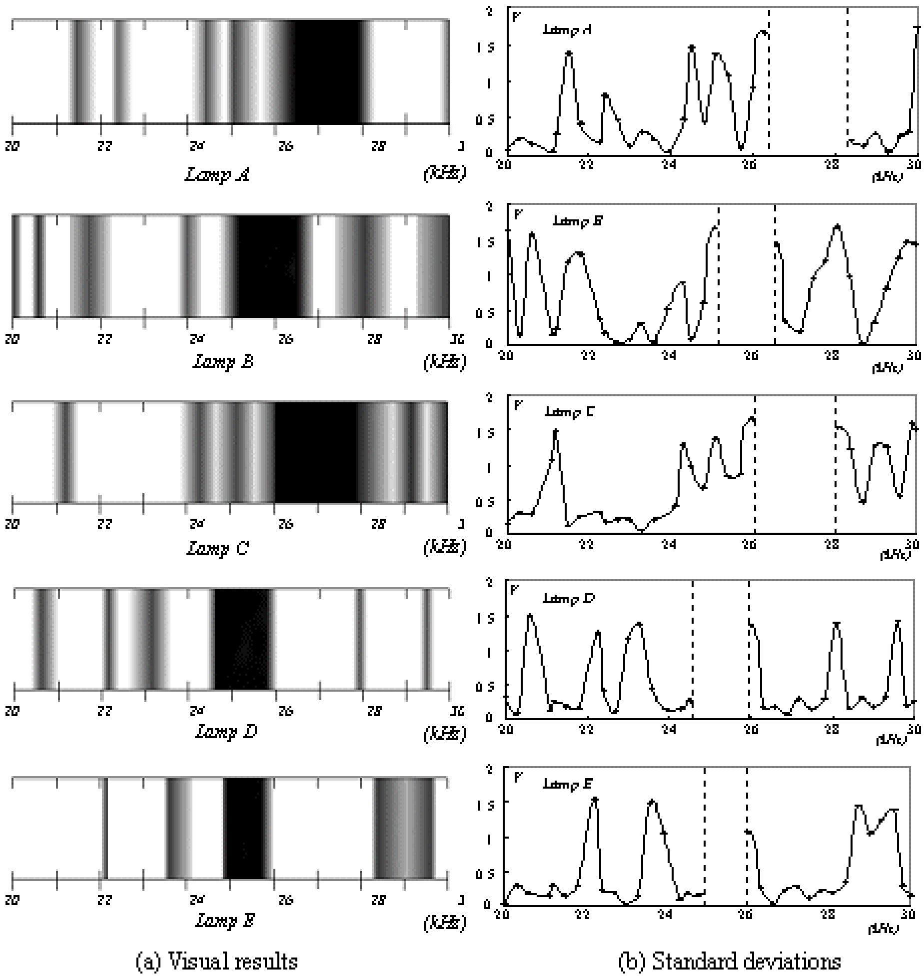

Figure 4: Visual results and voltage standard deviation for different metal-halide lamps.

lamp voltages along with the visual results for five lamps over the frequency range from 20 kHz to 30 kHz. Observing these results, the verdict that standard deviation of lamp voltage less than 0.3V signifies the absence of acoustic resonance, is sustained. Lamps A, B, and C are of the same type from the same manufacturer, however, their frequency spectra of acoustic resonance differ to some extent. Lamps D and E are from different manufacturers, the frequency spectra of acoustic resonance are different even more. All these lamps have a frequency band in which the arc may be characterized by a serious acoustic resonance.

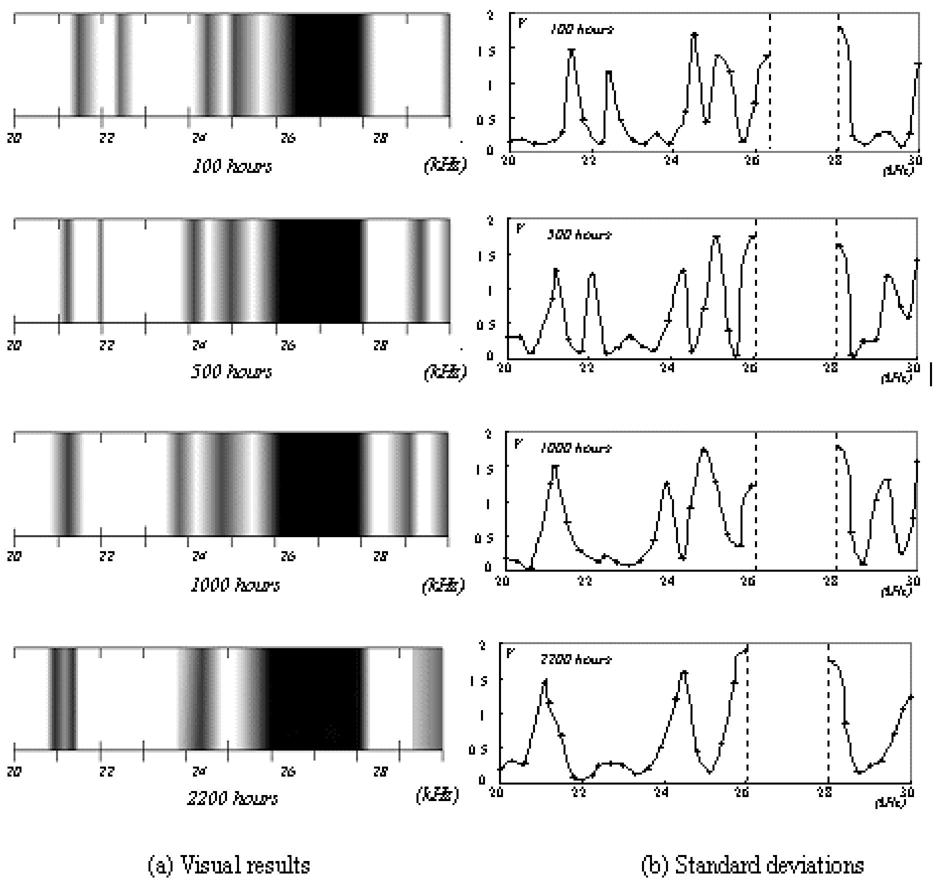

Figure 5: Visual results and voltage standard deviation for the lamp of different used hours.

Fig. 5 illustrates another experiment over the influence of lamp used hours on acoustic resonance. These figures show test results for the lamp used after 100, 500, 1000, and 2200 hours. The standard deviations of the lamp voltages for these tests are very similar to each other. Accordingly, it can be concluded that the used hours do not have significant effect on acoustic resonance. Nevertheless, compared to the visual results, the voltage standard deviations really are consistent with the occurrence of acoustic resonance.

On the purpose to discern the influence imposed on operating power, a lamp is deliberately operated at half of its rated power, i.e. 35W. Fig. 6 represents the measured standard deviation of lamp voltages in logarithmic scale at the operating frequency. The lamp is tested under the frequency range of 20∼ 50 kHz and lamp output power is adjusted at 35W and 70W alternatively. The discontinuous curve is due to the extinguished arc too, and the dashed lines denote the boundary of acoustic resonance happening, that is, 0.3V. The experimental results show that the voltage deviations at half of the rated power are relatively smaller than at the rated power. By comparing these curves, it can be concluded that the lamp instability is generally alleviated at a reduced power.

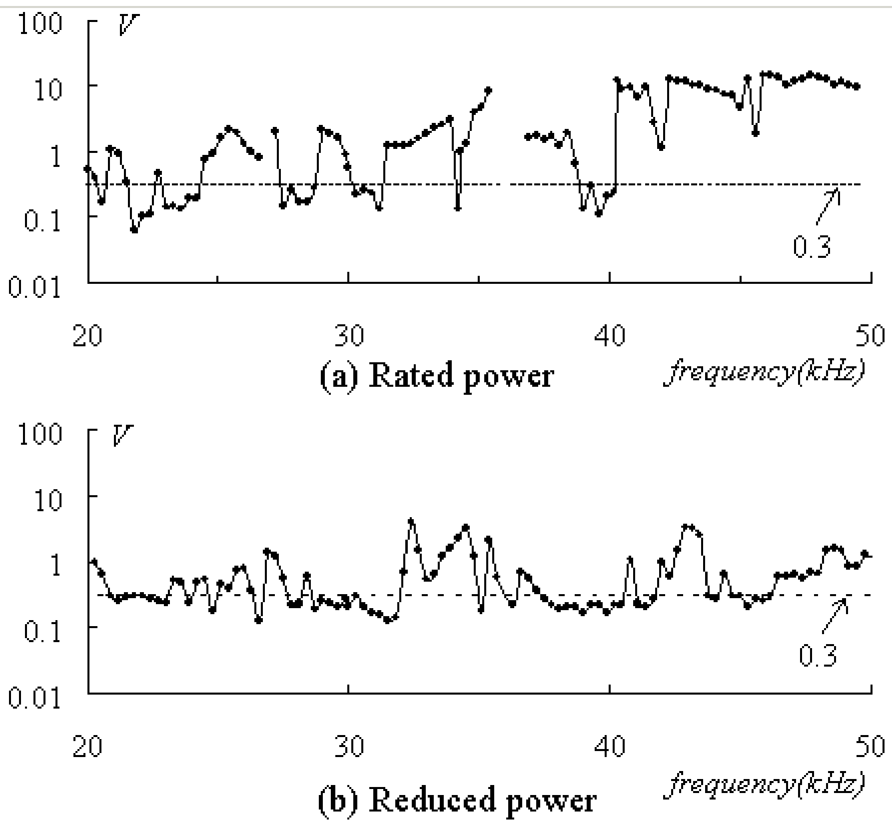

Figure 6: Standard deviation of lamp voltage.

5 Conclusions

The glittering of metal-halide lamp light output in the presence of acoustic resonance implies that there is electrical input variance in the lamp. The lamp voltage variation is found to be more dominant than other parameters. Therefore, the standard deviation of the lamp voltage can be used as an index to determine the occurrence of acoustic resonance. The usage of this index has been verified by the experiments over different types of metal-halide lamps and lamps of different used hours. From the test results, it is found that the frequency spectra of acoustic resonance are different from lamp to lamp even though they are of the same type from the same manufacturer, while the lamp used hours do not have significant effect on acoustic resonance. Therefore, an electronic ballast can be designed to operate the specified lamp with pre-knowledge of its frequency spectrum of acoustic resonance, and this spectrum may not be agitated by lamp used time span. The lamp power is manifested to be a factor to affect the instability of metal halide lamps, while operating at a reduced power will alleviate the problem of acoustic resonance.

The standard deviation of the lamp voltage can be obtained from the on-line measurement, and thus can be used for detecting the occurrence of acoustic resonance in a very short time. Then, the protection or control strategy can be designed accordingly.

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