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# Experimental Measurement of Arc Motion and Light Flicker Frequencies in the HID Lamps

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***Abstract***

*In order to reduce the electric consumption for high intensity discharge lamps, the use of high frequencies electronic ballasts represents both a solution and many advantages such as the decrease in the congestion and low costs. However, high frequency operation is not regarded as perfectly reliable due to the appearance of acoustic resonances inside the arc tube, which can result in low frequency light flicker and even lamp destruction. Here we experimentally determined light flicker frequencies using a photodiode which detects the light intensity fluctuation for a high intensity discharge lamp of 50W. Additionally, the arc motion frequencies are determined with the aid of a camera. The results obtained are compared with those of a lamp of the same type but with different power (35W).*

***Keywords***: *Acoustic resonance, fast fourier transform FFT, photodiode, Arc Motion, CMOS image sensors*



## 1. Introduction

Lighting is one among numerous applications in which the electric discharge is important. At first low pressure lamps dominated the market as the first artificial luminous sources, then the development of high intensity discharge lamp permitted the creation of light sources producing an important luminous flow. This flow permitted the lighting of wide public spaces. The difference is that the volume in high intensity discharge lamps presents an improvement in regard to that of low pressure lamps, in addition to the lamp life and a better control of its functioning, thus reducing electricity consumption [1].

These lamps prove to emit light at a high lumen output levels with a very high quality of colour. Low frequency drivers operate the HID lamps, operating these lamps at a high frequency high to 300 kHz achieve an efficency enhancement, but the alternative current generates a periodic heat source in a form of plasma discharge arc [2 - 4].

Pressure oscillations are implied by the fluctuating temperature field, a material flow is generated through an acoustic streaming phenomenen by the induced standing pressure waves, this happens when the driving current is at acoustic Eigen frequency of the arc tube. The buoyancy driving velocity field is then affected, as a consequence, arc motion or high intensity fluctuations are created. We have measured current, voltage, electric power for the determination of the acoustic resonance frequencies. The flickers at that step of work are not investigated a lot [5 - 7].

In our paper, we investigated the frequency of light intensity flicker and discharge arc motion too. To determine the frequency at various operating parameters and the time dependant behaviour, the use of measurements with photodiode is involved. A camera is used to record the arc motion so as to identify the shape and position of the arc, thus determining the arc motion frequency. Our findings are compared to those obtained for the same type of lamps at a power of 35W.

## 2. Experiment Description

The LFWS, low frequency square wave setup used to measure the acoustic resonance spectra of HID lamps uses a square wave plus ripple signals (SWPR) as power supply. A low

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frequency (LF) square signal is modulated in amplitude by a high frequency (HF) sinusoidal signal at different modulation depths, this type of signal result into various power components associated to different frequencies. Each frequency component dependency lies on the desired modulation depth so as to be measured for characterising the system [7 - 9]. We presented the setup used to the measurements in Figure 1. The function generator (FG1, YOKOGAWA FG 300) generates a sinusoidal (HF) signal acting as modulation for the (LF) square signal generated by FG2 (Agilent 3312A). At FG2 output the SWPR is created, this signal then is amplified by power amplifier and the amplified signal is delivered to the resistor which tests the presence of HID lamp (Philips 50W, 930Elite). Both a power analyser (YOKOGAWA pz4000) and an oscilloscope (Lecroy 6030A) are used to measure the input of the resistor; both of them monitor the current and the voltage. The oscilloscope is used to create the Fast Fourier Transform of the power signal (obtained by direct multiplication of the current and voltage input channels) [9 - 10].

We measured the power in the frequency domain of the DC signal (frequency 0), the modulation frequency (HF), and the carrier frequency (LF). We used a high speed silicon photodetector to measure brightness fluctuations during discharge arc flicker. The incident light is converted into current thanks to the photodiode.

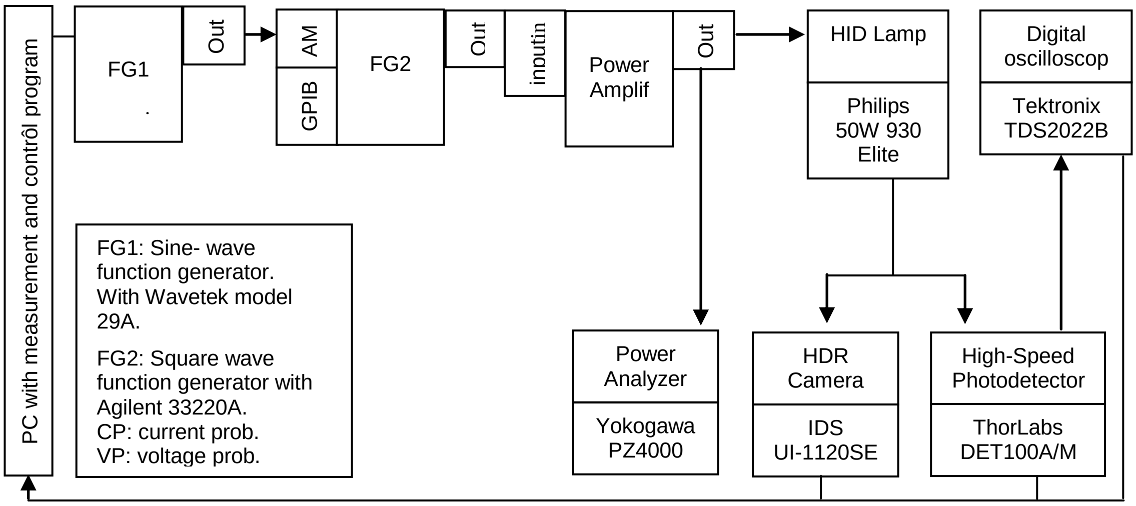


Figure 1. LFSW setup characterization of discharge arc flicker in HID lamps

This electrical signal is continuously transformed into frequency domain by Fast Fourier Transform (FFT) by a digital oscilloscope (Tekonix TDS2022B), Flicker frequency is the result, besides all findings are registered every 5 s for further work [10-12].

So as to measure the time dependant arc deflection we used a camera of a high dynamic range (due to the high brightness differences between the electric arc and the surrounding) which records video of the brightness distribution of the discharge arc. In the arc tube center, the deflection is calculated for each frame and used as marker for arc motion. The motion frequency is created through a process by which the time signal is segmented into 5s then after converted by FFT into a frequency domain [13-15]. The lamp is 0,2 m far from the other devices, the camera and the photodetector, all put at the same horizontal level. The data saving and setup control is monitored by computer [16-17].

First of all the lamp is operated at a stable condition for 2 minutes, this is before the measurement. Then the sinusoidal excitation frequency is set to a frequency near the first acoustic Eigen frequency of the arc tube. The modulation depth is set to a value high enough to stimulate fluctuations of the arc discharge. The HID lamps operated at 90% of its nominal power so as to limit power input during discharge arc flicker [17-19].

**3. Results**

We adjusted the frequency flicker characterisation to $42 \pm 2$ kHz, since most frequent investigations about first acoustic Eigen frequency is done with lamps types approximate to 42 kHz ones. At first we presented both flicker and motion frequencies at a fixed excitation frequency of 42 kHz and a modulation of 15%, then we present discharge arc flicker around the first acoustic Eigen frequency as a function of excitation frequency and modulation depth.

A 2D brightness distribution of the discharge arc is used to determine the motion frequency (Figure 2a and Figure 2b); the course of maximal brightness is displayed by the black lines in the figures. Arc deflection is the definition of the vertical distance between this curve and the horizontal symmetrical line (z = 0).

Figure 2b represents the moment of the maximal arc deflection; the high intensity is depicted at the moment of minimal arc deflection, 50 mn later. The time difference results in a periodic time of 100 ms and motion frequency of 10 Hz equal to sinusoidal half circle.

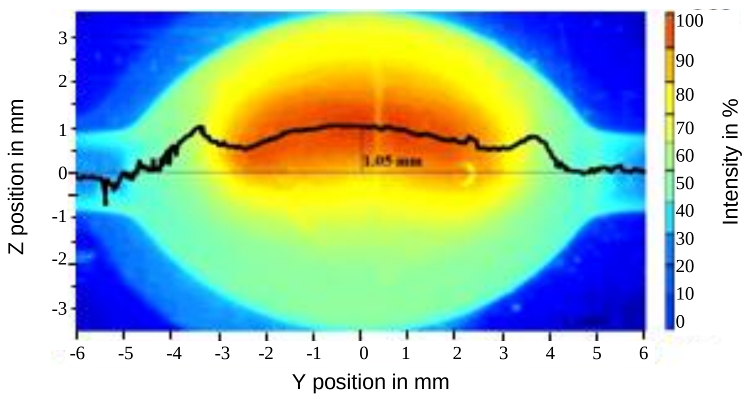


Figure 2a. Distribution of light intensity for an excitation frequency of 42 kHz and 15% of the modulation depth in stable condition

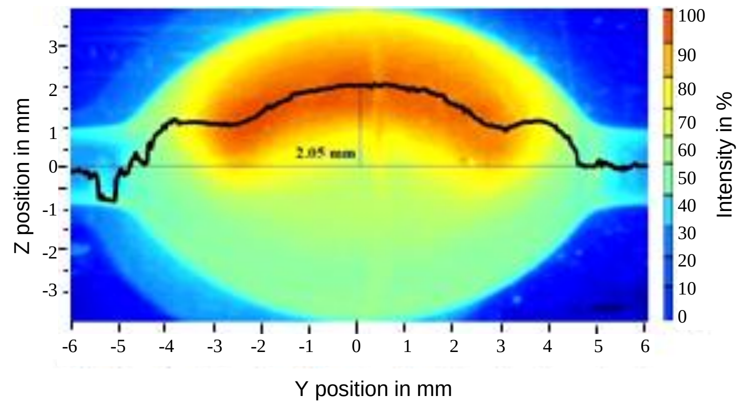


Figure 2b. Distribution of light intensity for an excitation frequency of 42 kHz and 15% of the modulation depth after 2 min

The same experiment done but this time with a lamp of 35W appeared a deflection of 1.35 mm while in the case of a 50W lamp, the deflection is of 2.05 mm.This difference is mainly due to the ohmic effect within the arc discharge. The difference in ohmic losses plays an important role in raising the temperature within the plasma. In parallel when the temperature of the arc increases, the buoyancy caused by the gravitational force increases too, therefore the discharge arc deflection will be larger.

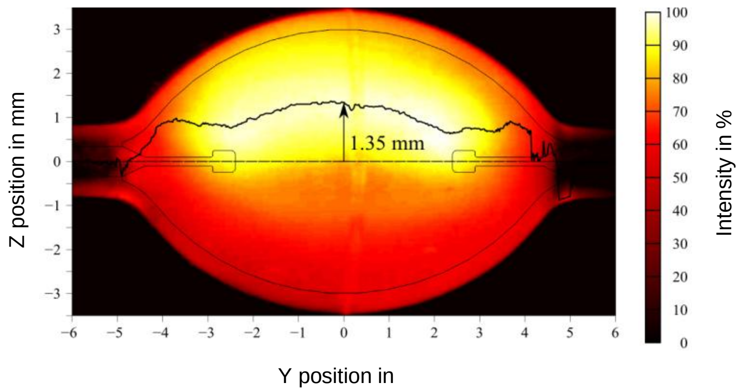


Figure 3. Distribution of light intensity for an excitation frequency of 42 kHz concerning a HID lamp of 35W

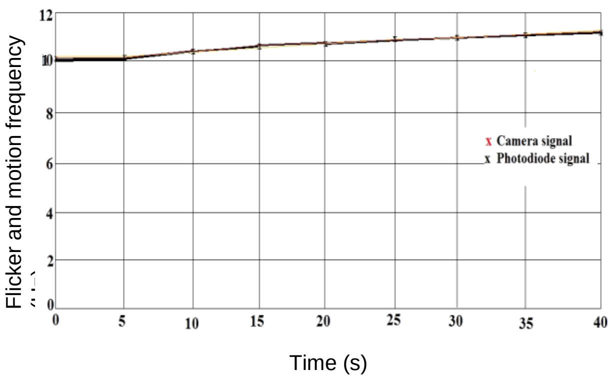


Figure 4. Motion frequency and flicker frequency in the frequency domain for HID lamp 50W

Figure 4 displays the flicker time development during 40s, we observe that the two frequencies raise from below 10 Hz to 11 Hz. This increasing flicker frequency over time can be noticed in almost all measurements and we noticed that both measurements are in a very good agreement. The arc motion frequency and the light intensity flicker frequency are similar.

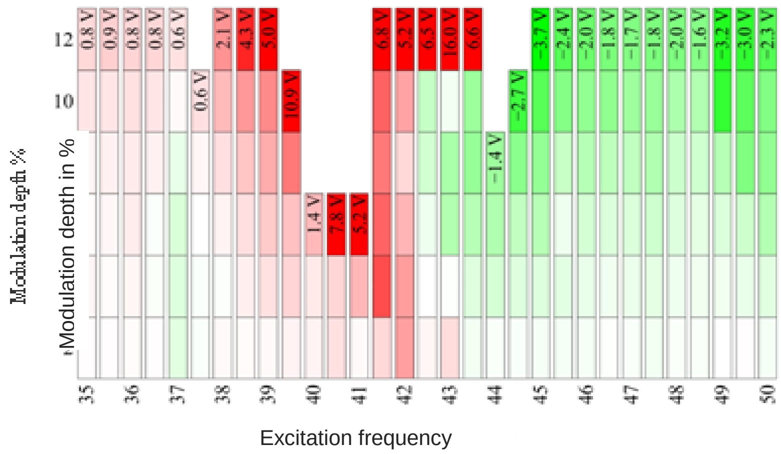


Figure 5a. Flicker as function of excitation frequency and modulation depth for HID lamp 50W

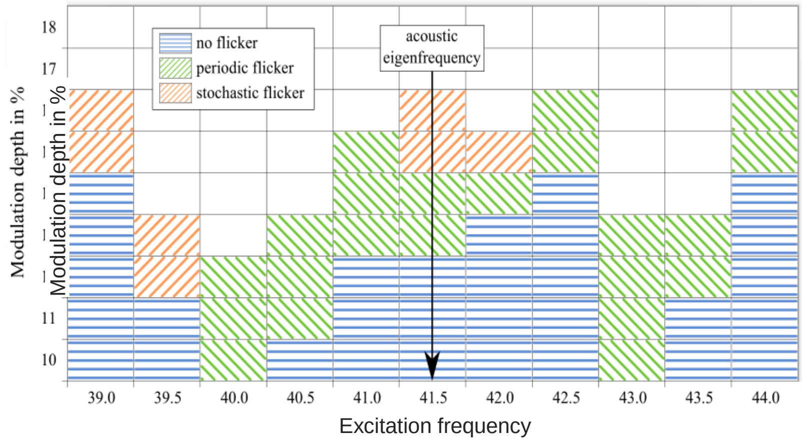


Figure 5b. Flicker as function of excitation frequency and modulation depth for HID lamp 35W

In order to characterize arc flicker near the first acoustic Eigen frequency, for the 50W HID lamp, the excitation frequency is raised from 35 kHz to 50 kHz in 500 Hz scale and the modulation depth is set to values between 2% and 12% in steps of 2%. While for the 35W HID lamp, we used a modulation depth from 10% to 16% in step of 2% and an excitation frequency from 39 to 44 kHz.

Figure 5a and Figure 5b display the findings and comparison is made. During measurements no flicker has been observed indicates the green box. The magenta colour marks operating parameters at which periodic flicker and the red boxes high light operating parameters at which a stochastic behaviour of the flicker has been detected. The initial frequency increases with increasing excitation frequency in both 50W and 35W lamp and in the case of periodic flicker.

In the case of HID lamp 50W we remark that at excitation frequencies of 35 kHz to 38 kHz there is just the periodic flicker, whereas at the starting point of the excitation frequency from 38.5kHz to 43.5 kHz the stochastic flickers begin to occur especially at the modulation of 11%, whereas in the HID lamp 35W case, the stochastic flicker appears only in 4 values of excitation frequency 39, 39.5, 41.5 and 42 kHz.

As a result there is an agreement between the tow kinds of lamps, the stochastic flickers start to occur in the surroundings of the first Eigen frequency for each lamp. In fact both the arc motion and light intensity flicker frequencies are similar. The two lamps excitations frequencies are very approximate to the exact acoustic Eigen frequency. The superimposed acoustic fields interact differently, the absolute value of arc deflection raises in parallel to the modulation depth because the force that arises from acoustic streaming effect is increased by the high excitation power. Then we conclude that the discharge arc is directed upward since the value of the arc deflection is positive at periodic flicker.

## 4. Conclusion

We conclude that the filcker frequencies of light intensity measurements with photodiode and motion frequencies of arc deflection measurements with camera are in good coherence, after characterization of the discharge arc in HID lamps at different excitation frequencies near the first acoustic Eigen frequencies for HID lamps 50W and 35W. Therefore, we deduce that the frequency periodic flicker increases with increasing excitation frequency at frequencies approximate the Eigen frequency. The flicker frequency is significantly lower and the stochastic motion occurs above a precise value of the modulation depth characterised of each type of lamp.

The temperature distribution changes in the arc tube introduce a movement of the plasma arc, a different acoustic streaming field results from the changing temperature field, consequently affecting the flicker frequency. For this reason, we will focus our next work on the effect of distribution arc temperature on the increase of the flicker frequency.

**Acknowledgment**

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