Keep It Simple and Learn More - on a Stationary Study of a Time-Dependent Problem

B. Baumann[1], J. Schwieger[2], U. Stein[1], M. Wolff[1]

[1]Hamburg University of Applied Sciences, Hamburg, Germany
[2]Hamburg University of Applied Sciences, Hamburg, Germany, University of the West of Scotland, Paisley Campus, United Kingdom

Abstract

Today's driver hardware for High-intensity discharge (HID) lamps is bulky, expensive and not particularly energy-efficient. A downscaling of the devices seems possible by increasing the operation frequency from typically 400 Hz to some hundred kilohertz. However, efforts to design high-frequency lamp-driver systems were not successful, since the periodic Joule-heating generates sound waves, which are resonant inside the arc tube containing the plasma. The acoustic resonances (AR) lead to undesirable effects like light flicker and a reduction of the lamps' lifetime.
The processes inside the arc tube exhibit a rich dynamic, in particular when the plasma arc becomes unstable near an AR. To overcome the light flicker problem requires an understanding of the details of the mechanisms that lead to the instability and numerical simulations are the natural means to obtain insights. A first attempt to simulate the plasma behavior near AR with COMSOL Multiphysics® software reaches back to 2008. The model used then was two-dimensional and time-dependent. To obtain a more realistic description of the lamp we set up a three-dimensional model. We deliberately restrict ourselves to a stationary model. The idea is to identify physical instabilities by loss of convergence of the simulations while varying the driving frequency.
Our plasma model comprises balance equations for mass, electric charge, momentum and energy. The occurrence of acoustic streaming (AS) is important for the formation of light flicker. Therefore, it is necessary to couple an acoustic model to the plasma model. Instead of using the full viscothermal acoustic model (differential equations for acoustic pressure, acoustic temperature and sound particle velocity), we describe the propagation of sound waves by the Helmholtz equation. Acoustic loss effects are incorporated by loss factors. Since a boundary layer is a prerequisite for the generation of AS, it was introduced artificially. For the coupling of the acoustic model to the plasma model it is necessary to implement a recursion loop.
The voltage drop between the electrodes in a frequency range comprising the lowest lying acoustical mode is depicted in the left part of the figure. It behaves differently in frequency upward- and downward scans, which is the signature of a hysteresis. We observe that the voltage jumps to a higher/lower value at certain frequencies. The hysteresis and the jump phenomenon are well known from the Duffing oscillator. The response of the Duffing oscillator is depicted in the right part of the figure. The similarity of the two systems is striking and the jumps offer a natural explanation for instable behavior.
We have set up a COMSOL Multiphysics® model for the calculation of the behavior of the

arc tube filling of an HID lamp. The focus was on the impact of AS on the stability of the plasma arc. The main finding is that light flicker can be linked to the jump phenomenon known from the Duffing oscillator. This connection would not have been revealed without the simplification from a time dependent to a stationary model.

Figures used in the abstract

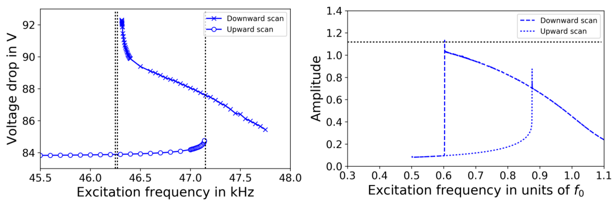

Figure 1: Left: Voltage drop of HID lamp near first acoustic resonance frequency. Right: Response of Duffing oscillator with a softening spring.