3D Acoustic Streaming Field in HID Lamps

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Introduction: High-intensity discharge (HID) lamps will in the foreseeable future be important light sources despite a growing market share of LEDs. Cost and energy efficient high frequency (300 kHz) operation is hampered by the excitation of acoustic resonances inside the arc tube which results in low frequency (10 Hz) light flicker. Our aim is to calculate the acoustic streaming (AS) velocity field, which is related to the sound waves, and link it to arc flicker. In contrast to the approach in [1] the model is 3 dimensional.

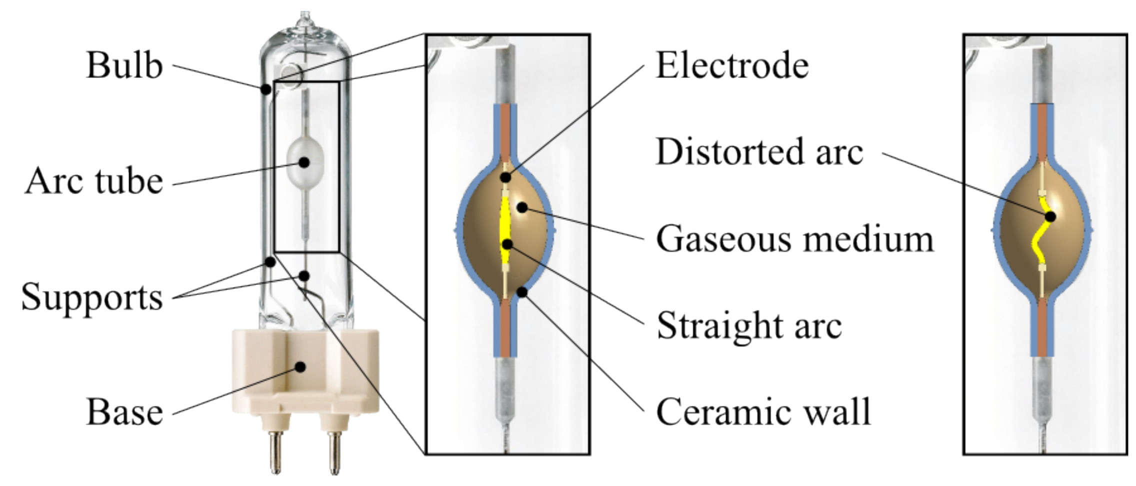

Figure 1. Design of Philips 35 W 930 Elite HID lamp (left) and Arc perturbation in vertical lamp operation (right).

FE Model: The model comprises three parts. The first part consists of a set of equations, which serve to calculate the temperature distribution inside the arc tube (Figure 2).

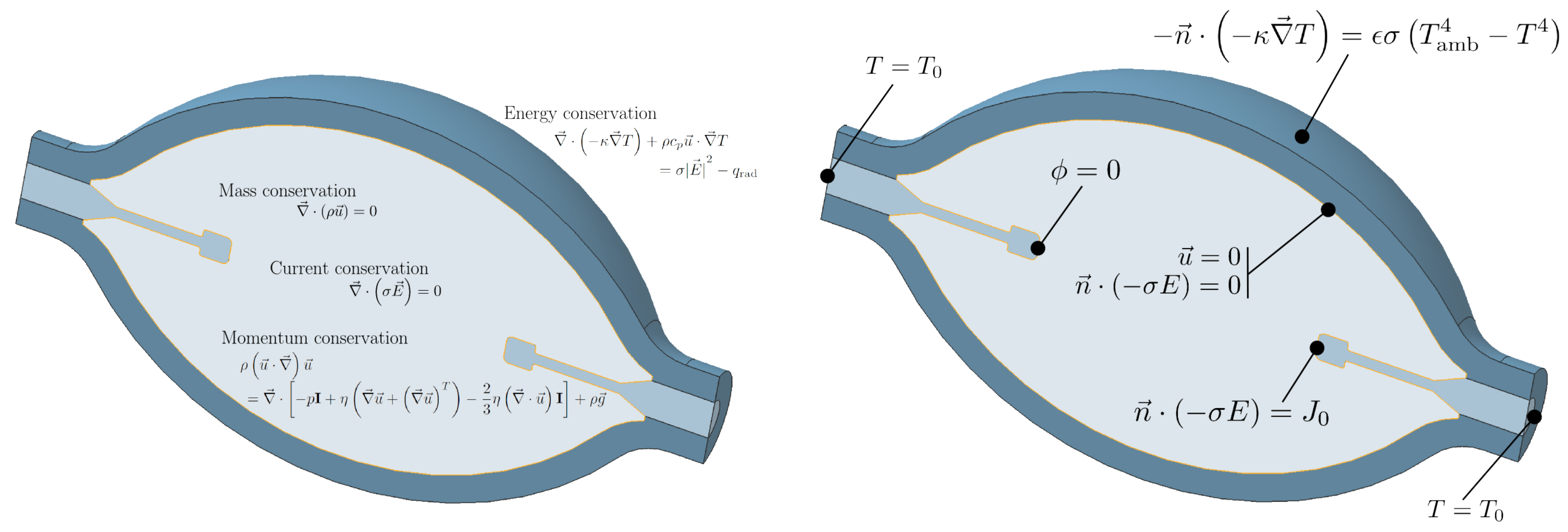

Figure 2. Differential equations and boundary conditions used for the calculation of the temperature field.

In the second part the acoustic response is calculated via expanding the acoustic pressure in eigenmodes. The sound velocity is space dependent since it depends on the temperature field. Damping effects are included via loss factors [2]. In a last step the AS velocity field is calculated by solving the Navier-Stokes equation once again. The external force term is calculated from the sound particle velocity (the bar indicates the time average):

$$f_l = \frac{\partial \rho \overline{\tilde{u}_k \tilde{u}_l}}{\partial x_k} - \delta_{l3} \rho g.$$

Before inserting the sound particle velocity into this equation, it is necessary to multiply it with a factor that accounts for the influence of the viscous boundary layer [2].

Results: In Figure 3 the streaming field obtained with our model is depicted. From the color scale one can read that maximal streaming velocity is about 0.8 m/s. This value is consistent with the results reported in [1]. This seems to be a large velocity inside a vessel of diameter of 6 mm. So it does not appear surprising that the plasma arc is severely disturbed by the streaming field. In Figure 4 the same velocity field is displayed in a 2D plot. A close look reveals that the general structure is the same as in the right part of Figure 4 (two by two vortexes rotating in certain directions), which has been derived analytically for a simpler, but otherwise similar situation. This we take as a further confirmation that the model works properly.

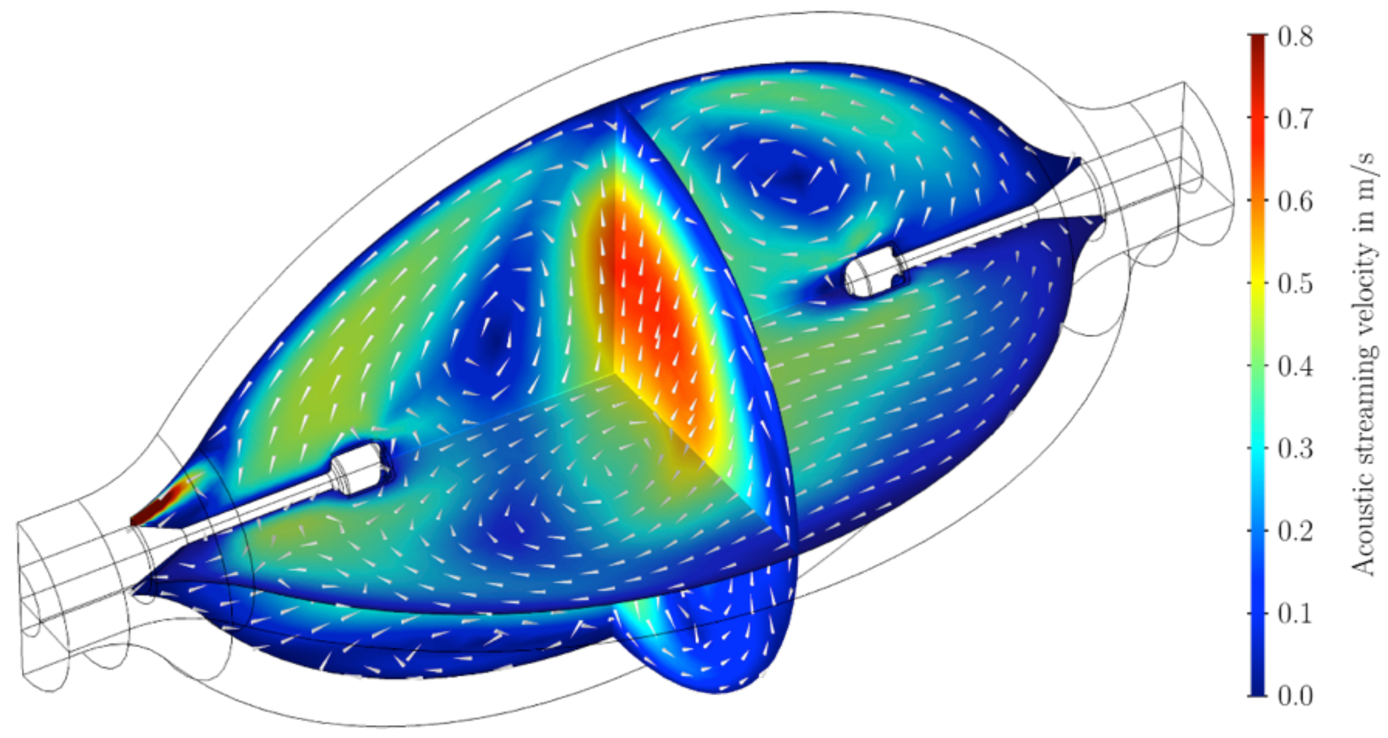

Figure 3. Streaming field obtained from the model.

The flow pattern depicted in the left part of Figure 4 is asymmetric. It is well known that in nonlinear dynamic systems symmetry breaking can occur. In these systems a symmetry gets lost once a certain control parameter rises above a critical value. In order to test if this happens here we calculated a series of streaming fields with the force term as a control parameter. It has been found that the symmetry is restored when the force becomes weaker. We conclude that the streaming field suffers symmetry breaking.

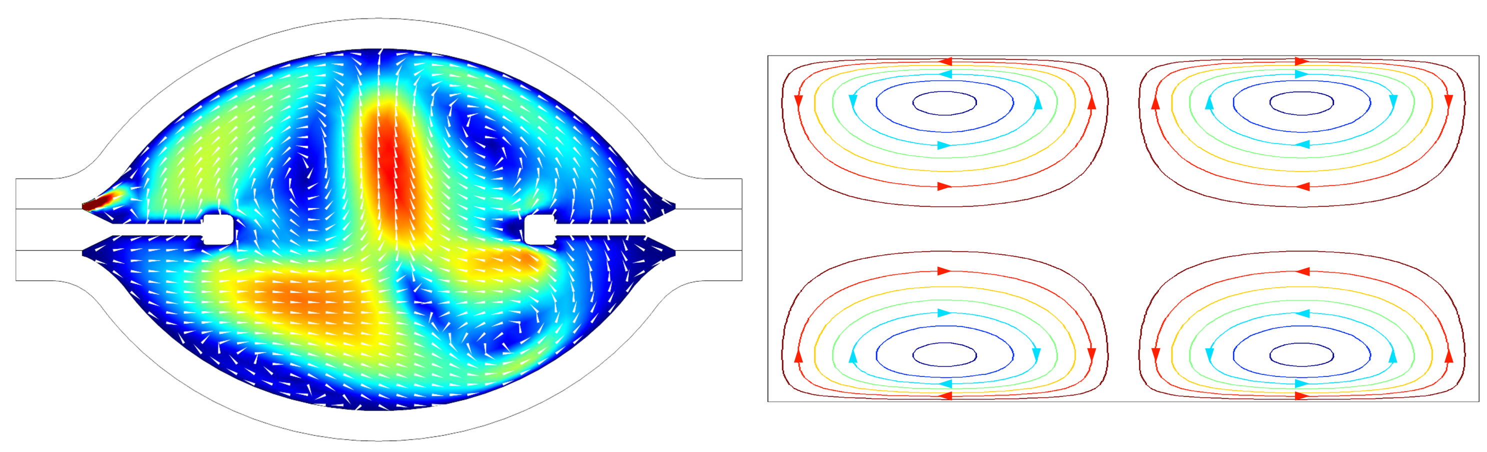

Figure 4. Streaming field inside arc tube (left) and streaming field resulting from longitudinal modes in a cylinder [2] (right).

Conclusion: A stationary 3D model for the calculation of the AS field inside the arc tube of HID-lamps has been developed. The results obtained are consistent with theoretical expectations. It has been found that the streaming field suffers a symmetry breaking transition with the streaming force as control parameter. It has been confirmed that AS is very likely the mechanism responsible for light flicker.

References:

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