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ELECTRODE-LESS FERRITE-FREE CLOSED-LOOP INDUCTIVELY-COUPLED FLUORESCENT LAMP

Oleg A. Popov, Pavel V. Starshinov, and Victoriya N. Vasina

National Research University Moscow Power Engineering Institute (NRU MPEI)
E-mail: popovoleg445@yahoo.com

ABSTRACT

Electrode-less ferrite-free inductively-coupled low pressure discharge was excited in the mixture of mercury vapour (~10^{-2} Torr) and argon (0.1 Torr) at a frequency of 2.0 MHz and lamp *RF* powers of (150–202) W with the help of a 6-turn induction coil. The discharge lamp of rectangular shape (50 cm in length and 7 cm in height) employed a closed-loop glass tube of 30 mm in diam. Tube walls inner surface was coated with three-color phosphor (T_{cc} = 3100 K, R_a = 80). The induction coil made from silver-coated copper wire (ρ_w = 2.2x10^{-3} Ohm/cm) was disposed on the atmospheric side of tube walls, along closed-loop lamp tube perimeter. As plasma power, P_{pl}, grew from 127W to 180 W, coil power losses practically were unchanged, P_{coil} = (25–22) W. Lamp luminous flux, Φ_v, grew with plasma power from 10430 lm (P_{pl} =127 W) to 13500 lm (P_{pl} =180 W), while plasma efficacy, $\eta_{pl} = \Phi_v/P_{pl}$, decreased from 82 to 75 lm/W, and lamp efficacy $\eta_V = \Phi_v/(P_{pl} + P_{coil})$ decreased from 70 to 67 lm/W.

Keywords: ferrite-free inductive discharge, fluorescent lamp, low pressure mercury plasma, coil power losses, lamp and plasma efficacy, radiofrequency voltage (*RF*)

1. INTRODUCTION

Transformer-type inductively-coupled light sources excited in the mixture of low pressure mercury vapour and inert gas at *RF* frequencies (0.1–13.56) MHz and *RF* power (50–500) W have shown excellent characteristics: high luminous efficacy (up to 100 lm/W) and very high life-time (> 60000 h) [1, 2]. However, transformer-type lamp has one but substantial disadvantage: expensive and fragile ferrite cores encircling a closed-loop discharge tube. Meanwhile, ferrite-free inductively-coupled discharges could be excited at *RF* frequencies in a closed-loop lamp made from a tube of (50–70) mm in diameter with the help of an induction coil disposed on the atmospheric side of lamp walls, along its “inner” perimeter [3].

Here, we present results of an experimental study of ferrite-free closed-loop inductively-coupled lamp employing discharge tube of 30 mm in diameter excited with the help of an induction coil encircling the lamp around its “outer” perimeter.

2. EXPERIMENTAL SET-UP AND MEASUREMENT TECHNIQUES

An inductive plasma was excited and maintained at a frequency *f* = 2.0 MHz and *RF* power of P_{pl} = (127–180) W in the mixture of mercury vapour and argon in a closed-loop lamp made from cylindrical glass tube of 30 mm in diam. Tube walls inner (vacuum) surface was coated with three-colour phosphors (T_{cc} = 3100 K, R_a = 80). The lamp has rectangular shape of 500 mm in length and of 70 mm in height; the distance between two discharge tubes was H_2 = 6 mm (Fig. 1). A 6-turn induction coil made from silver-coated copper wire (ρ_w = 2.2x10^{-3} Ohm/cm) encircled the closed-loop discharge lamp along its perimeter. Mercury vapour was maintained at optimum pressure of ~ 10^{-2} Torr by controlling amalgam (Bi-In-Hg) temperature; argon pressure was 0.1 Torr.

Sinusoidal *RF* voltage at a frequency of 2,0 MHz was sent from the signal generator (PM 5193, Philips) to the wideband amplifier (A-300, ENI), and further to the directional coupler (C5100, Werlatone). Forward and reflected *RF* power, P_{for} and P_{ref}, were measured with the help of *RF* power meter (NAP Z8, Rhode-Schwartz). The transferred *RF* power $P_{tr} = P_{for} - P_{ref}$ comprised plasma absorbed power, P_{pl}, induction coil power losses, P_{coil}, and *RF* power P_{cap} dissipated in low loss (<1 W) matching network ceramic capacitors C_{ser} and C_{par}. Induction coil *RF* voltage and current, U_c and I_c, phase shift between them, φ, and lamp and matching network powers, P_{lamp} and P_{cap}, were measured with the help of high voltage probe, current transformer, and 4-channel oscilloscope HP 54503A. Lamp luminous flux, Φ_v, spectrum, and lamp colour characteristics, T_{cc} and R_a were measured with the help of the computerized photometrical sphere. Plasma and lamp efficacy were calculated as $\eta_{pl} = \Phi_v/P_{pl}$, and $\eta_v = \Phi_v/P_{lamp} = \Phi_v/(P_{pl} + P_{coil})$, respectively.

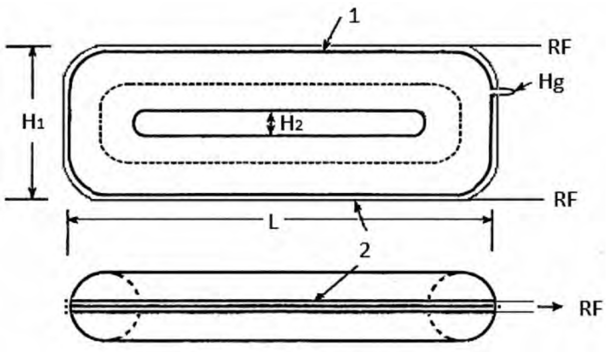

Fig. 1. Schematic drawing of ferrite-free closed-loop inductively-coupled lamp: 1 – discharge tube; 2 – induction coil; Hg – exhaust tubing with amalgam; RF – radio-frequency voltage

2. EXPERIMENTAL RESULTS AND DISCUSSION

The results of measurements are shown in Figs. 2, 3. It is seen from Fig. 2 that coil power losses, P_{coil}, did not show dependence from plasma power, P_{pl}, and had values of (22–25) W. Lamp luminous flux, Φ_v, grew as plasma power increased from 10430 lm (P_{pl} =127 W) to 13500 lm (P_{pl} = 180 W). Coil power efficiency $\eta_c = 1 - P_{coil}/(P_{pl} + P_{coil})$ increased with plasma power from 0,85 (P_{pl} = 127 W) to 0,89 (P_{pl} = 180 W), while lamp and plasma efficacies, η_v and η_{pl}, decreased from 70 to 67 lm/W, and from 82 to 75 lm/W, respectively (Fig. 3). The decrease of plasma efficacy η_{pl} as plasma power grew was due to the growth of the frequency of quenching collisions of resonantly excited mercury atoms with plasma electrons [3, 4].

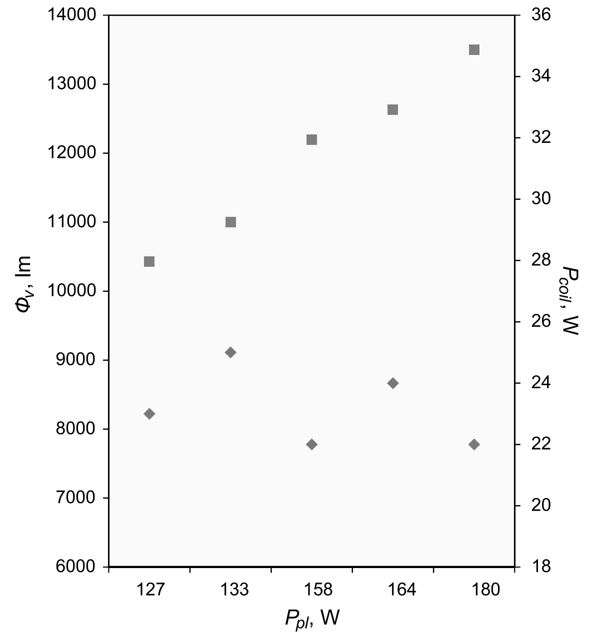

Fig. 2. Lamp luminous frux, Φ_V, and induction coil power losses, P_{coil}, as functions of plasma power, P_{pl}. ■ – Φ_V; ♦ – P_{coil}

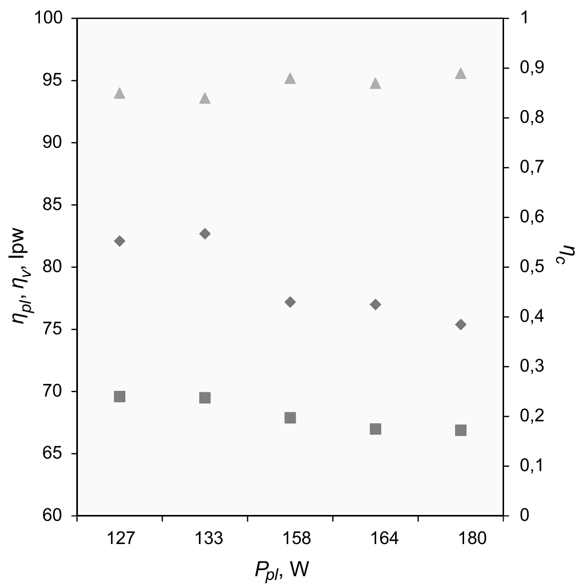

Fig. 3. Lamp and plasma efficacies, η_v and η_{pl}, and induction coil power efficiency, η_c, as functions of plasma power, P_{pl}. ♦ – η_{pl}; ■ – η_V; ▲ - η_c

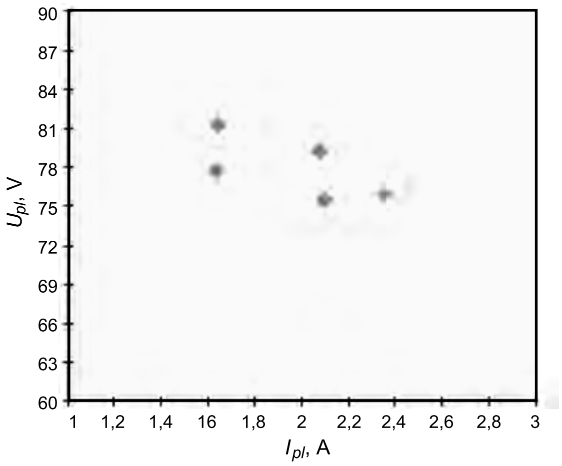

Fig. 4. Lamp volt-ampere characteristic, U_{pl} *vs* I_{pl}

Discharge current, I_{pl}, calculated within the framework of inductive discharge transformer model grew with plasma power from 1.63 A (P_{pl} = 127 W) to 2.35 A (P_{pl} = 180 W). While *RF* electric field, $\bar{E}_{pl}$, averaged across plasma diameter, decreased insignificantly from 0.76 to 0.72 V/cm. These values are essentially the same as *RF* electric fields (E_{pl} = (0.73–0.78) V/cm) in the transformer lamp plasma excited in mixture of mercury vapour (~10^{-2} Torr) and argon (0.1–0.12 Torr) in the closed-loop tube of 16.6 mm in diam. at a frequency of f = 265 kHz and plasma power of P_{pl} =180 W [5]. The dependence of plasma *RF* voltage, U_{pl}, from discharge current, I_{pl}, plotted in Fig. 4 has negative character and is in good agreement with the dependence of $\bar{E}_{pl}$ from P_{pl} that is typical for high density low pressure mercury discharges [4].

3. CONCLUSION

It was experimentally shown that plasma efficacy 80 lm/W and lamp efficacy 70 lm/W could be obtained in a ferrite-free closed-loop inductively-coupled mercury low pressure fluorescent lamp with discharge tube of 30 mm in diam. The further increase of plasma efficacy η_{pl} could be achieved by rising argon pressure to (0.2–0.3) Torr, at which ultraviolet UV (λ = 254 nm) radiation generation in the inductive discharge in the closed-loop lamp with tube of 16,6 mm in diameter operated at the same power level was found to be maximal [5]. To substantially increase lamp efficacy, $\eta_V = \eta_c\eta_{pl}$, induction coil efficiency, η_c, should be increased to 0,95–0,97 by reducing coil power losses to (4–5) W. This could be done by using in induction coil low loss ($\rho_w \leq 5\text{x}10^{-4}$ Ohm/cm) Litz wire [3].

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Oleg A. Popov,
Prof., Dr. of Science, graduated from MPEI in 1965, Professor at the chair "Light and Engineering" NRU MPEI

Pavel V. Starshinov,
M. Sc., graduated from NRU MPEI in 2015, post graduate student at the chair "Light and Engineering" NRU MPEI

Victoriya N. Vasina,
student of the chair "Light and Engineering" NRU MPEI