Equivalent Circuit and Electrodynamic Characteristics of Waveguide-Based Nozzleless Cylinder-Type Microwave Plasma Source

Michał Sobański [1], Mieczysław Lubański [1], Mariusz Jasiński [1], Jerzy Mizeraczyk [1, 2]

[1)] Centre for Plasma and Laser Engineering, The Szewalski Institute of Fluid-Flow Machinery, Polish Academy of Sciences J. Fiszera 14, 80-231 Gdańsk

[2)] Department od Marine Electronics, Gdynia Maritime University, Morska 81-87, 81-255 Gdynia, Poland

INTRODUCTION

We present equivalent circuit of existing waveguide-based nozzleless cylinder-type microwave plasma source (MPS). The waveguide-based cylinder-type MPS was used to convert methane into hydrogen. This MPS operates at atmospheric pressure and frequency of 2.45 GHz. The discussed cylinder-type MPS is based on rectangular waveguide WR 430. Equivalent circuit presented in this paper cannot describe all electrical properties of the real MPS accurately, due to some structural elements, which electrical lumped equivalents are difficult to find or are unknown. We used Comsol Muliphysics software to calculate some of them. The plasma column plunges partially into cylinders (non-symmetrically) creating two lossy coaxial lines. The central "wire" of this lossy coaxial lines is plasma column. Plasma is strongly non-linear element of the circuit because plasma impedance Z_p depends on incident microwave power.

FORMULAS

Transformation factors:

$$k_T = \frac{Y_0}{Y_{01}} \qquad k_S = \frac{Y_{01}}{Y_0} = k_T^{-1}$$

Normalized movable plunger susceptance in output plane:

$$b_S = \frac{B_S}{Y_0} = ctg\left(\frac{2\pi}{\lambda_g} \cdot l_S\right) = t_S^{-1}$$

Plasma impedance:

$$Z_p = R_p + jX_p$$

Normalized input admittance:

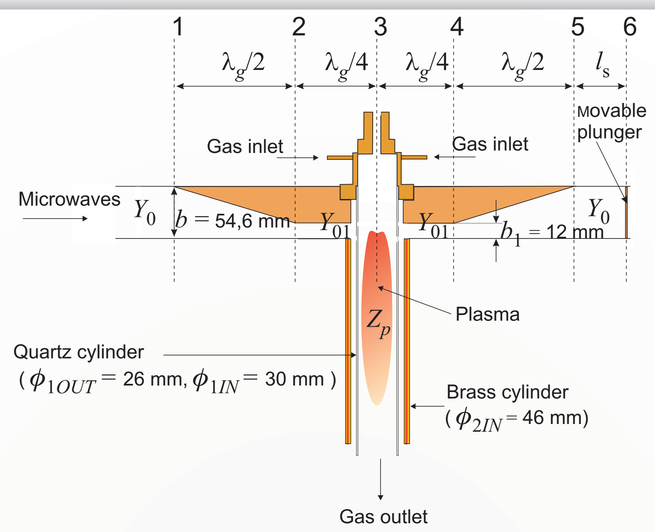
$$y_{in} = \frac{Y_1}{Y_0} = k_S \frac{Z_p^{-1} \cdot (Z_b Y_{01} - jb_S) + Y_{01}}{Z_a[Z_p^{-1}(Z_b Y_{01}^2 - jk_S Y_o b_S) + Y_{01}^2] - jk_S Y_0 b_S}$$

Tuning characteristic:

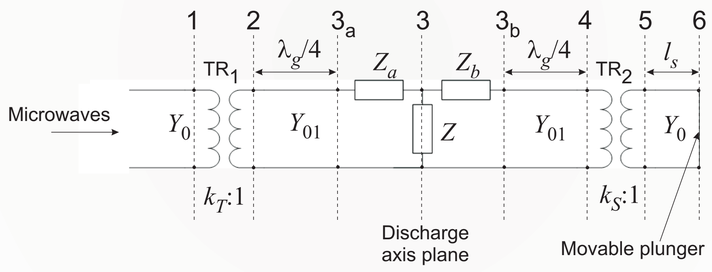
$$\frac{P_R}{P_I}\left(\frac{l_S}{\lambda_g}\right) = \left|\frac{y_{in} - 1}{y_{in} + 1}\right|^2$$

where P_I and P_R are the power of incident and reflected waves respectively, R_p and X_p are the plasma resistance and reactance respectively, Y_1 is input admittance.

MICROWAVE PLASMA SOURCE



Sketch of the MPS



Equivalent Circuit of the MPS

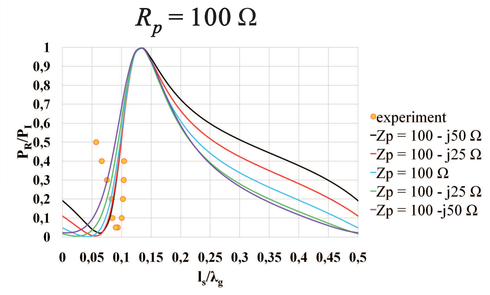
Quantity	*Description*
λ_g	Wave length in standard WR 430 waveguide
l_S	Movable plunger position
$Y_0 = 1/Z_0$	Characteristic admittance of standard WR 430 waveguide
Z_0	Characteristic impedance of standard WR 430 waveguide
$Y_{01} = Y_{02}$	Characteristic admittance of reduced height b_1 section
ϕ_{2IN}	Inner diameter of brass cylinder
Z_p	Plasma impedance
Z_a, Z_b	Impedances representing discontinuity (holes) in reduced height waveguide
k_T, k_S	Transformation factors of the input and output transformer respectively
a, b	Standard WR 430 waveguide width and height respectively

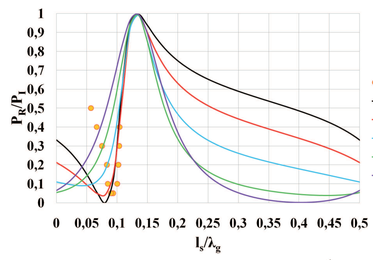
TUNING CHARACTERISTICS

Quantity	*Value*
λ_g	147.7 mm
Z_0	357.5 Ω
$Y_{01} = Y_{02}$	12.7 mS
Z_a, Z_b	j33.5 Ω, j72.22 Ω
a, b	109.2 mm, 54.6 mm

Experimental data for:
- *Nitrogen flow rate 200 l/min*
- *Input power 2kW*

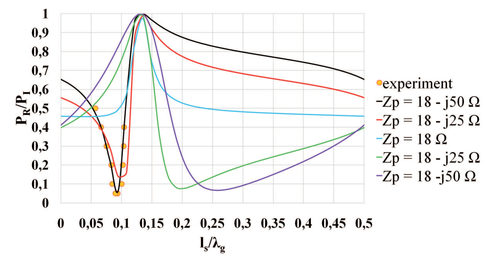
$R_p = 100\ \Omega$





$R_p = 50\ \Omega$

$R_p = 18\ \Omega$



CONCLUSIONS

- **The calculated results and results achieved in experiment are very similar for assumed plasma resistance $R_p = 18\ \Omega$ and plasma reactace $X_p = -50\ \Omega$.**
- **The power reflection coefficient P_R/P_I of the MPS is small (below 0.1) for narrow range of normalized movable plunger position**

This research was supported by The National Centre for Research and Development (NCBiR) under programme NR 14-0091-10/2010