PLASMA CHARACTERISTICS IN SQUARE PULSE ARC DISCHARGE OF PLASMA CATHODE ELECTRON SOURCE DEVICE

KARAKTERISTIK PULSA KOTAK PLASMA ARCH DISCHARGE DALAM PIRANTI SUMBER ELEKTRON KATODA PLASMA

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ABSTRACT

PLASMA CHARACTERISTICS IN SQUARE PULSE ARC DISCHARGE OF PLASMA CATHODE ELECTRON SOURCE DEVICE. *Plasma parameters in Plasma Cathode Electron Source Device (PCESD) are very important things because they will determine the eficiency of its electron extraction. Square pulse mode of PCESD's arc discharge plasma current can be obtained by using Pulse Forming Network (PFN) circuits which is called Arc Discharge Power Supply (ADPS). The square pulse mode is necessity to simplify in electron irradiation dose calculation. ADPS is connected with Hollow Anode Chamber (HAC) which is placed inside of PCESD to produce arc discharge plasma. The value of arc discharge plasma current is the main key to determine plasma parameters that can be measured by using Rogowski coil. The value of the arc discharge plasma current is* I_{ADPS} *= 206.30 A with pulse width* τ *= 80 µs. Whereas the plasma parameters values inside of the HAC are: the electron plasma density* $n_e = (16.85 \times 10^{19})\ m^{-3}$*, electron plasma temperature* T_e *= 2.609 eV, electron plasma frequency* f_e *= 116.74 GHz, and Debye length* λ_D *= 9.958 µm respectively.*

Keywords : Arc discharge, plasma cathode, hollow anode, Rogowski coil, Debye length.

ABSTRAK

KARAKTERISTIK PLASMA DALAM LUCUTAN BUSUR PULSA KOTAK DARI PIRANTI SUMBER ELEKTRON KATODA PLASMA. *Parameter plasma dalam Piranti Sumber Elektron Katoda Plasma (PSEKP) adalah sesuatu yang sangat penting karena akan menentukan efisiensi ekstraksi elektronnya. Bentuk pulsa kotak dari arus plasma lucutan arc PSEKP dapat diperoleh dengan menggunakan rangkaian Jaringan Pembentuk Pulsa (JPP) yang dinamakan Arc Dicharge Power Supply (ADPS). Bentuk pulsa kotak sangatlah diperlukan untuk menyederhanakan dalam perhitungan dosis iradiasi elektron. ADPS dihubungkan dengan Bejana Anoda Berongga (BAB) yang terletak di dalam PSEKP untuk menghasilkan plasma lucutan busur. Besarnya arus plasma lucutan busur merupakan kunci utama untuk menentukan parameter plasma dan ini bisa diukur dengan menggunakan koil Rogowski. Besarnya arus plasma lucutan busur yang diperoleh adalah sebesar* I_{ADPS} *= 206,30 A dengan lebar pulsa* τ *= 80 µs. Sedang besar parameter plasma di dalam BAB masing-masing adalah: kerapatan plasma elektron* $n_e = (16{,}85 \times 10^{19})\ m^{-3}$*, suhu plasma elektron* T_e *= 2,609 eV, frekuensi plasma elektron* f_e *= 116,74 GHz dan panjang Debye* λ_D *= 9,958 µm.*

Kata kunci : Lucutan busur, katoda plasma, anoda berongga, koil Rogowskil, panjang Debye.

INTRODUCTION

Large cross section electron beams are attractive for applications involving large plane objects or bulk media. They have found use in radiation technologies, in surface modification of structural materials, in pumping the active media of gas lasers, and in other fields [1-3]. In Plasma Cathode Electron Sources, the production of beams of this type is accomplished by the extraction of electrons from the surface of volumetric plasma.

Plasma parameters in Plasma Cathode Electron Source Device (PCESD) are very important things because they will determine the efficiency of its electron extraction. For simplicity in electron dose irradiation, the square pulse mode is necessity. Plasma parameters in square pulse arc discharge of Hollow Anode Chamber (HAC) can be determined by using Rogowski coil (for measuring the electron plasma beams current) and voltage divider probe for measuring the high voltage pulse [4].

HAC is placed inside of the Plasma Cathode Electron Source Device (PCESD). HAC is cylindrical shaped which made of SS 304 with its diameter of 4.00 cm and length of 48.75 cm as well as PCESD chamber is also cylindrical shaped, made of SS 304 with its diameter of 16.00 cm and length of 82.00 cm. There are igniter electrodes in the HAC which consist of the massive cylindrical cathode made of silver (Ag) material and cone shaped of anode made of SS 304 material and then between anode and cathode is separated by ring shaped isolator of teflon material. HAC (as an anode) and igniter cathode are separated by cylindrical shaped isolator of coprolon material.

Plasma is formed in the HAC after arising plasma spot on the silver (Ag) cathode surface of igniter electrode system due to the potential different from cathode (igniter electrode system) to the anode (HAC). The arising plasma spot is driven by 12 kV Ignitor Discharge Power Supply (IDPS), then this spot ignites plasma formation in the HAC which is driven by 1 kV Arc Discharge Power Supply (ADPS) [5]. The goal of this experiment is to determine the plasma parameters in the HAC, which are electron plasma density n_e, electron plasma temperature T_e, electron plasma frequency f_e and Debye length λ_D.

METHODOLOGY

Photograph of the experiment device unit of Plasma Cathode Electron Source is shown in Fig. 1. The experiment is carried out by pressure of 10^{-4} torr, the output voltage of IDPS is 12 kV and the ADPS output voltage is 1 kV.

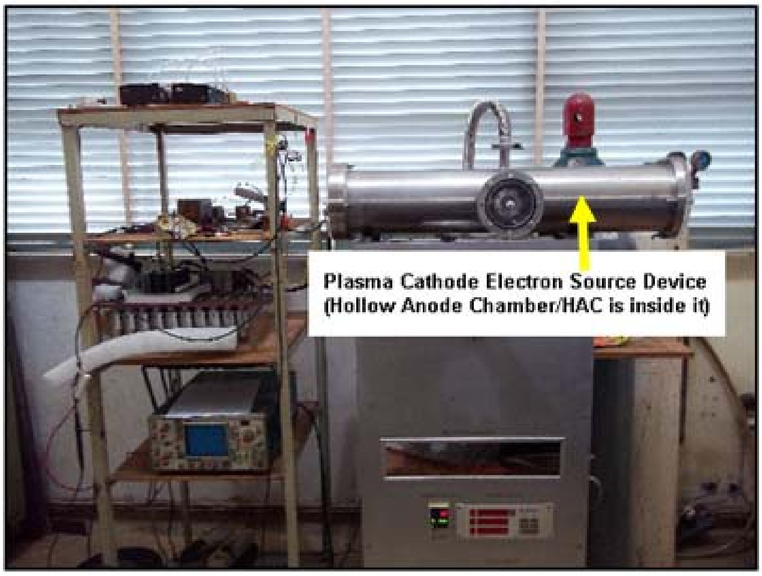

FIG. 1. Photograph of the experiment device unit of Plasma Cathode Electron Source .

Schematic of HAC is displayed in Fig. 2. It is shown that negative pole of ADPS which is connected to IDPS cathode, the positive pole is connected to HAC (anode 2). HAC module has the igniter electrodes for forming plasma spot. The igniter electrode materials of HAC use silver (Ag) as a cathode and SS 304 as an anode. The anode and cathode are separated by ring shaped isolator of teflon material while the HAC with igniter cathode is separated by cylindrical shaped isolator of coprolon material.

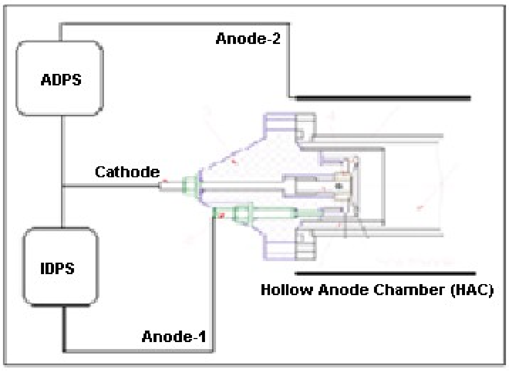

FIG. 2. Schematic of Hollow Anode Chamber (HAC)

Photograph of ADPS's Pulse Forming Network (PFN) circuits to form the square pulse mode of PCESD's arc discharge plasma current is shown in Fig. 3. PFN which consists of a 10 meshes of C-L circuits with 1 μF/1.2 kV capacitance and 27 μH inductance.

Photograph of the Rogowski coil with 80 winds for measuring the high beams current of arc discharge plasma is shown in Fig. 4, while the parameters of its apparatus is shown in Table 1.

FIG. 3. Photograph of ADPS's Pulse Forming Network (PFN) circuits

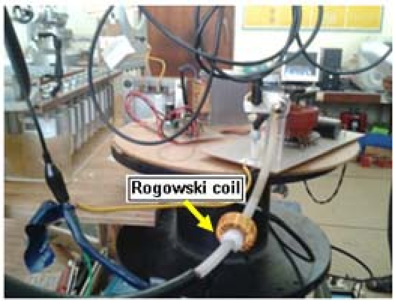

FIG. 4. Photograph of Rogowski Coil with 80 winds

Table 1. Parameters of Rogowski coil apparatus

No.	Parameter's Name	Simbol	Value (Unit)
1	Outer diameter	$Ø_{luar}$	28 mm = 28 x 10^{-3} (m)

2	Inner diameter	$Ø_{dalam}$	14.24 mm = 14.24 x 10^{-3} (m)
3	Middle diameter	$Ø_{tengah}$	21.12 mm = 21.12 x 10^{-3} (m)
4	Toroid thickness	t_t	11 mm = 11 x 10^{-3} (m)
5	Toroid width	L_t	6.88 mm = 6.88 x 10^{-3} (m)
6	Toroid radius	r_{toroid}	10.56 mm = 10.56 x 10^{-3} (m)
7	Wire diameter for wind	$Ø_{kawat}$	0.4 mm = 0.4 x 10^{-3} (m)
8	Wire radius for wind	r_ℓ	0.2 mm = 0.2 x 10^{-3} (m)
9	Wind number	N	80 winds
10	Rogowski coil cross section	A_{kR}	75.68 mm = 75.68x10^{-3} (m)
11	Relative permeability	μ_r	93 Henry/Ampere
12	Air permeability	μ_0	4π x10^{-7} Henry/Ampere

RESULT AND DISCUSSION

Plasma spot in HAC occurs 1 mm in front of igniter electrodes surface and it is driven by IDPS voltage of 12 kV with tube pressure about of 10^{-4} torr while the arc discharge plasma occurs inside of HAC and it is driven by ADPS voltage of 1 kV. The photograph of arc discharge plasma that occurs inside of HAC and electron beam supposed that emitted from one side of hole of HAC are shown in Fig. 5.

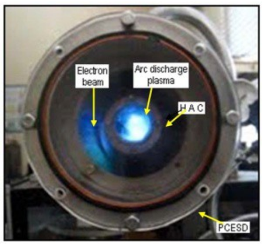

FIG. 5. Photograph of arc discharge plasma inside of the Hollow Anode Chamber (HAC)

The arc discharge plasma current is measured by using Rogowski coil. Photograph of arc discharge plasma current which is expressed in the form of square pulse of output voltage having pulse high of 10 V and pulse width of 80 μsec is shown in Fig. 6.

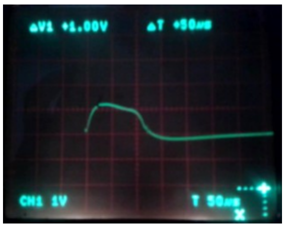

FIG. 6. Photograph of the output voltage of Rogowski coil measurement.

The arc discharge current (I_{ADPS}) is given by following formulation [6]:

$$I(t) = \frac{2\,\pi\,a\,R\,C}{\mu_0\,A\,n}\;V_0(t) \tag{1}$$

It is obtained the ADPS current I_{ADPS} = 206.30 ampere (A) with the values of a = torus major radius = 10.56 × 10^{-3} m, R = integrator resistance = 100 Ω, C = integrator capasitance = 0.33 × 10^{-6} F, V_0(t) = measured voltage = 10 volt, μ = permeability constant = $\mu_o \times \mu_r$ = 93 (4 $\times 10^{-7}$) Hm^{-1}, A = torus minor crosss section = 75.68 $\times 10^{-6}$ m^2 and n = number of torus wind = 80 winds.

By using simulation it has been chosen that the optimum radius of plasma beam current is r = 3.00 µm so by substituting the optimum discharge plasma current $I_{opt.}$ = 206.30 A and r = 3.00 µm into formulation 2,

$$J_r = \frac{I_{opt}}{\pi r^2} \tag{2}$$

and it is obtained the value of plasma current density $J_{(r:3\mu m)}$ = 730 x 10^8 A/cm^2.

The total charge value of Q in the HAC is formulated by :

$$Q = I \tau \tag{3}$$

It is obtained the value of Q = 16.50 $\times 10^{-3}$ coulomb (C) with the plasma discharge current I = 206.30 A and the τ = 80 µs. Hence the total number of of electrons in the HAC the $N \approx 10^{17}$ electrons 1 C = 6.25 $\times 10^{18}$ electrons. The volume V of HAC is known by substituting its dimension of radius r = 2.00 cm and the length l = 48.75 cm. The plasma density in the HAC can be determinated by:

$$n_e = \frac{N}{V} \tag{4}$$

The plasma density value is obtained n_e = (16.85 $\times 10^{19}$) m^{-3}. Resulting n_e = (16.85 $\times 10^{19}$) m^{-3} is still ten to hundred times higher than expected value. It is happened because the applied vacuum degree is still lower that expected, had not yet reached 10^{-4} torr.

Electron temperature T_e can be determinated by using the relation [7] :

$$T_e = \frac{16 \pi m_e J_r^2}{8 e^2 n_e^2 k} \tag{5}$$

The value of electron temperature T_e can be calculated by using the value of plasma current density $J_{(r:3mm)}$ = 7.3 $\times 10^6$ A/m^2 and electron density n_e = (16.85 $\times 10^{19}$) m^{-3} that have been determined before, and the other values of constant are known as m_e = electron mass = 9.109 $\times 10^{-31}$ kg, e = electron charge = (1.602 $\times 10^{-19}$) C, and k = Boltzmann constant = 1.381 $\times 10^{-23}$ J/K. It has been calculated that the value of plasma temperature T_e = (3.0269 $\times 10^4$) K = 2.609 eV. This temperature value has been in agreement with the expectation.

For ion plasma frequency f_i is not able to be calculated because the total ion charge Q_i and the ion plasma density n_i in the HAC has not yet been determined, while the electron plasma frequency f_e can be deduced by:

$$f_e = 8980 \sqrt{n_e} \tag{6}$$

The electron frequency depends on the electron density n_e (in cm^{-3} unit) that has been determinated n_e = (16.85 $\times 10^{13}$) cm^{-3}, and it has been calculated by using Eq. (6) that the obtained value of electron plasma frequency is f_e = 116,740 $\times 10^6$ Hz = 116.74 GHz. This frequency value is on the range of micro wave band (several of Giga Hertz).

By using the values of electron plasma temperature T_e = (3.0269 $\times 10^4$) K and electron plasma density n_e = (16.85 $\times 10^{19}$) m^{-3} that have been determined and by substituting both of them:

$$\lambda_D^2 = \frac{\varepsilon_0 k T_e}{e^2 n_e} \quad or \quad \lambda_D = 743 \sqrt{\frac{T_e}{n_e}} \tag{7}$$

the value of Debye length can be obtained i.e. λ_D = (995.836 x 10^{-8}) m = 9.958 µm.

CONCLUSION

Based on the characterization discussion as described above can be concluded as follows. The plasma parameters determination in the HAC of SS 304 cylinder shaped with 2.00 cm radius and 48.75 cm length has been done. It is carried out on vacuum pressure about of 10^{-4} torr, igniter output voltage of 12 kV on IDPS and 1 kV on ADPS to produce arc discharge plasma. The arc discharge plasma current I_{ADPS} = 206.30 amper (A) was obtained by using Rogowski coil as measurement device. The values of plasma parameters inside of the HAC are: the electron plasma density $n_e = (16.85 \times 10^{19})$ m^{-3}, electron plasma temperature $T_e = (3.0269 \times 10^4)$ K = 2.609 eV, electron plasma frequency $f_e = 116{,}740 \times 10^6$ Hz = 116.74 GHz and Debye length $\lambda_D = (995.836 \times 10^{-8})$ m = 9.958 μm respectively. The value of electron plasma density $n_e = (16.85 \times 10^{19})$ m^{-3} is still ten to hundred times higher than expected value. It happened because the applied vacuum degree is still lower than expected, that had not yet reached 10^{-4} torr.

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