

ELECTRON BEAM EXTRACTION TRAJECTORY AS A FUNCTION OF EXTRACTION VOLTAGE ON PULSED ELECTRON IRRADIATOR

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ABSTRACT

ELECTRON BEAM EXTRACTION TRAJECTORY AS A FUNCTION OF EXTRACTION VOLTAGE ON PULSED ELECTRON IRRADIATOR. It has been carried out the studying of electron beam extraction of from Pulsed Electron Irradiator (PEI) device using 3D Opera simulation program. In this study, the extraction voltage of PEI was varied to know its effect on extracted electron beam trajectory. Plasma electron beam from Plasma Generator Chamber (PGC) is extracted toward acceleration region by external high voltage (V) and then it is passed through the foil window of PEI for being irradiated to the sample. Methodology in Opera simulation program consists of how to get the relation equation of the electron beam current j_e with the extraction voltage V , usage of its shape and measurement of the both of grid system geometry and PEI. PGC is made of Stainless Steel (SS) with cylindrical shape in diameter of $\Phi = 30$ cm and length of $l = 90$ cm, electron extraction window as many as 975 holes on the area of (15×65) cm² with extraction hole cell in radius of $r = 0.3$ mm respectively, a cylindrical shape PEI chamber is made of SS in diameter of $\Phi = 70$ cm and length of $l = 130$ cm. Electron beam extraction from the plasma surface is showed in simulating (3D opera program) based on usage of plasma surface potential data of 150 V with extraction voltage which is varied by values of $V = 5$ kV, 10 kV, 20 kV, 30 kV and 100 kV. Simulation yield shows that the electron extraction beam current from PGC occurred when there is applied extraction voltage of $V = 20$ kV and successive the extraction current density becomes denser with increasing the extraction voltage V .

Keywords : plasma electron beam, extraction, PEI, PGC.

INTRODUCTION

As a support for the achievement of research activities target in 2016 at PSTA Batan Yogyakarta, it has been studied the electron beam extraction from the window of Plasma Generator Chamber (PGC) as well as the simulation of electron beam trajectory in the accelerator region of the Pulsed Electron Irradiator (PEI). Electron beam simulations were performed using the Opera 3D program on the basis of surface potential 150 V data with a high voltage extractor V being varied from 5 kV, 10 kV, 20 kV, 30 kV and 100 kV respectively.

A gas in PGC is heated to a temperature specific to the material then its constituent atoms will ionize into electrons and positive ions. If the heating in PGC is continued, that is by increasing the voltage between the two electrodes, the number of ions and electrons increases, so that when it reaches a certain limit, the charge will be in equilibrium with the constituent atoms into plasma. A quasi-neutral plasma is a mixture of particles; ions, electrons, free radicals and molecules/atoms that are sensitive to electric and magnetic fields [1].

The plasma cathode electron source module is a pulse electron beam generator where the electron beam is formed by the emission or extraction of electrons from the plasma surface within the PGC. The electron plasma is emitted outward to the accelerator zone through the grid hole (extraction system) mounted on the PGC wall. In the accelerator regions the electron beam is accelerated to a maximum speed by the Coulomb field using an external high voltage

EXTRACTOR VOLTAGE ON PULSED ELECTRON BEAM IN A RESONANT

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1. INTRODUCTION

Excited electron beams (EEL) are used in various applications, such as in the extraction of electrons from cathodes in vacuum tubes, in the production of X-rays, and in the generation of free electron lasers (FELs). In the present work, we will study the extraction voltage on a pulsed EEL in a resonant system. The system is assumed to be a simple one, consisting of a resonant cavity with a uniform magnetic field. The analysis is based on the assumption of a plane wave solution for the electromagnetic field. The extraction voltage is derived from the boundary conditions at the cathode surface. The results show that the extraction voltage is a function of the resonant frequency and the magnetic field strength. The voltage increases with the magnetic field strength and decreases with the resonant frequency.

2. ANALYSIS OF THE EXTRACTOR VOLTAGE

The resonant system is assumed to be a simple one, consisting of a resonant cavity with a uniform magnetic field. The analysis is based on the assumption of a plane wave solution for the electromagnetic field. The extraction voltage is derived from the boundary conditions at the cathode surface. The results show that the extraction voltage is a function of the resonant frequency and the magnetic field strength. The voltage increases with the magnetic field strength and decreases with the resonant frequency.

The plane wave solution for the resonant system is given by the following equations: The extraction voltage is derived from the boundary conditions at the cathode surface. The results show that the extraction voltage is a function of the resonant frequency and the magnetic field strength.

which is subsequently extracted to the target through the foil window on the vacuum chamber wall of the PEI. PEI devices with large and large-sized electron beam output will be very useful to be applied to a wide flat surface material. The PEI device is highly promising for use in a variety of industries including health for the toxic materials processing industries (natural rubber latex), surface modification of the semiconductor and polymer industries, and the food industry for pasteurization without damaging texture and nutrients, as well as for neutralization of waste [2-3].

Determination of discharge type in PGC whether with corona discharge, glow discharge and arc discharge will depend on value of trigger power supply utilization, plasma generator power supply and PGC geometric shape and size. In accordance with the system of Pulsed Electron Irradiator (PEI) that require large order discharge runs of up to hundreds of ampercs (A) and relatively small discharge voltages of tens of volts then arc discharge [4] should be used. The occurrence of electron beam emission from plasma surface through emission window can be shown from simulation result using Opera 3D program device, that is with geometry data input form and size of PGC and PEI, extraction / grid hole diameter and big extractor electron voltage. The similar simulation has been done using SIMION 8.1 software to study the behavior of electron beam extracted from electron gun in electron beam machine (EBM), especially the dependence of electron beam diameter size on the applied extraction voltage. The simulation of electron beam trajectory in PEI has also been carried out using SIMION 8.1 software.

The purpose of this research is to show the electron beam extraction process from the plasma surface through the extraction window on the PGC wall, and to obtain the relationship equation between the extraction voltage of the beam to the electron extraction current density to perform the simulation of the electron current file trajectory using the Opera program.

THEORY

The most specific circumstance in the PEI system is that the plasma has a positive potential for the discharge electrode [5]. For electrons to be able to overcome the potential barrier in order to be extracted from the plasma surface to the acceleration zone. The position of the plasma electron emission limits of the plasma source can occur in 3 (three) forms of the emitted plasma surface positions, which are influenced by the large parameters of plasma density and the magnitude of the external voltage electric field [6]. The position of the electron's emission limits from the plasma (source) surface will be convex-shaped when the plasma with high density and or weak of extractor electric field resulting in the electron beam is out of focus. For the value of plasma density match electric field then it will produce electron beams that are parallel to each other and the position of the electron's limit of emission from the plasma (source) surface will be flat. The position of the electron's limit of emission from the plasma (source) surface to be convex to the moment of low plasma density and or strong electric field will produce a focused electron beam.

Plasma has a positive potential to the wall that encloses it. The charge shell l_s is formed between the plasma surface and the wall of the plasma occupied material. The electrons move faster leaving the plasma at a rate greater than the more massive ionic velocity and the wall contained negatively to the plasma. The plasma potential relative to the wall (expressed in volts) depends on the size and shape of the geometry and the plasma parameters such as temperature and plasma density. The boundary layer is called the plasma sheath or sheath thickness is the shielding distance λ_D shown at the plasma potential versus distance (plasma to wall surface) as shown in Figure 1 [7].

The phenomenon of plasma electron extraction in PEI system is more complex than ion extraction from plasma. For the formation of the electron beam, the addition of the collector potential ϕ_k or the extraction voltage V must correspond to the rising velocity (v) and power

The first step in the analysis of the data is to determine the distribution of the variables. This is done by plotting the data on a graph and looking for any patterns. The next step is to calculate the mean and standard deviation of the data. This is done by using the following formulas:

The mean is calculated by adding up all the values and dividing by the number of values. The standard deviation is calculated by taking the square root of the variance. The variance is calculated by taking the average of the squared differences between each value and the mean. The formulas for these calculations are as follows:

Mean: $\bar{x} = \frac{\sum x_i}{n}$
Standard Deviation: $s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n}}$

RESULTS

The results of the analysis are shown in the following table. The first column shows the variable being measured, the second column shows the mean, and the third column shows the standard deviation. The data shows that the mean value for the variable is 12.5, with a standard deviation of 3.5. This indicates that the data is normally distributed and that the mean is a good measure of the central tendency of the data.

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(W) for the ion or electron. The current density of electrons to the collector of j_e at the relativistic particle velocity is given by the Boltzmann equation [8] as follows:

$$j_e = j_{e0} \exp\left(\frac{-e(\varphi_p - \varphi_k)}{kT_e}\right) \quad (1)$$

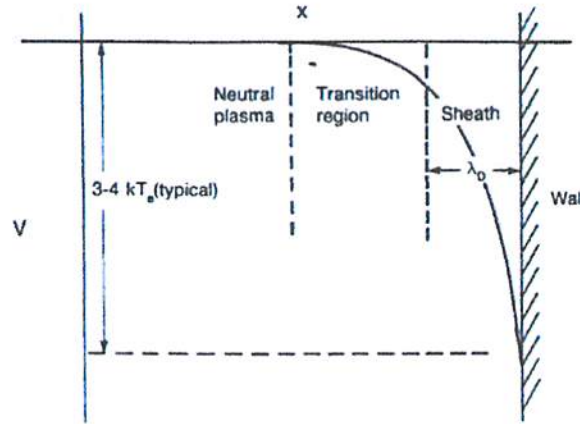


Figure 1. Potential plasma versus distance (plasma surface to the wall) [7].

and

$$j_{e0} = \frac{1}{4} e n_0 v \quad (2)$$

with j_{e0} is the electron current density of thermal plasma/maximum, e = electron charge = 1.602×10^{-19} C, φ_p = plasma potential, φ_k = collector potential, k = Boltzmann constant = $1,381 \times 10^{-23}$ J/K, T_e = plasma temperature, n_e = plasma density and v = electron relativistic velocity.

At the electron source, to extract the electron beam, an extraction voltage of V is applied to the cathode and the anode as shown in Figure 2 [9]. Shown in Figure 2 the formation of the plasma electron beam at a voltage V at the initial moment ($t = 0$) and then for the $t = 0$ the plasma electron boundary gradually moves toward the anode with velocity v_p .

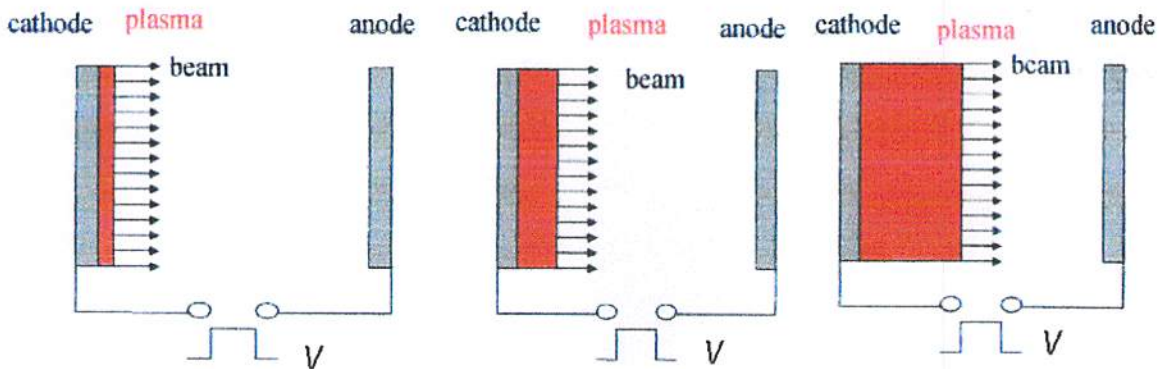


Figure 2. The beam-forming electrode of plasma development [9].

The extraction voltage V is determined by the following differential equation [10-11]:

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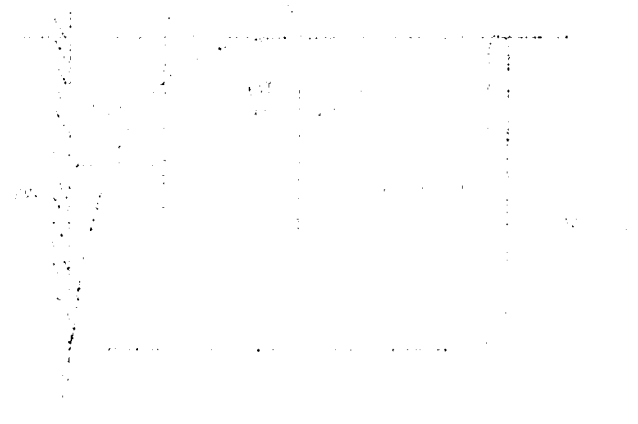


Fig. 1. Schematic diagram of the device for measuring the resistance of the contact.

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$$\frac{d^2V}{dx^2} = \frac{j_e}{\epsilon_0 \sqrt{2\eta} V^{1/2}} \quad (3)$$

with j_e is the density of the electron beam, ϵ_0 is the dielectric constant, η is the charge ratio with the electron mass (e/m) and V voltage applied to the anode-cathode terminal. This equation is solved by assuming that the area outside the electron stream is a charge-free region adjacent to the parallel plane of the electron flow region and the boundary condition $y < 0$ for the electron flow region and $y > 0$ for the charge free region (on the outer side of the electron flow). It is expected that the trajectory of the electron beam is aligned parallel to the axis and there is no change towards y then the relationship [11] is applied.

$$\frac{\partial V}{\partial y} = \frac{\partial V}{\partial z} = 0 \quad (4)$$

and

$$V = f(x) \quad (5)$$

with $f(x)$ is the solution which is the distance function electrode voltage and uses the $x + jy$ analysis function then [11].

$$V = \text{Real } f(x + jy) \quad (6)$$

$$V = \frac{1}{2} [f(x + jy) + f(x - jy)] \quad (7)$$

since V is limited symmetrically around $y = 0$, $\frac{\partial V}{\partial y} = 0$ at $y = 0$ then the parallel electron flow interpretation corresponds to the boundary conditions in the free region. For the flow of electrons from the cathode extracted through the anode gap of the voltage gradient is zero at zero potential, according to J.R. Pierce [11] by integrating equation (3) can be obtained

$$V = f(x) = \left(\frac{9j_e}{4\epsilon_0 (2\eta)^{1/2}} \right)^{2/3} x^{1/3} \quad (8)$$

Equation (8) can be used to calculate the magnitude of the potential to be mounted on a Pierce electrode with a focusing electrode angle of 67.5° to obtain an electron beam trajectory that is nearly parallel to the axis of the beam.

METHODOLOGY

Schematic of the Pulse Electron Irradiator (PEI) system is shown in Figure 3 [12]. The electron extractor anode (grid shape) mounted on the bottom of the PGC on the PEI system serves as a controller of the plasma electron emission currents extracted from the plasma surface. PEI consists of two electrode systems of producing plasma (2, 3 and 4) on the left and right side of PGC. The electrode systems have two power supplies, the trigger power supply (7) and the plasma generator power supply (8). The trigger power supply has a voltage specification of 10 kV, and the energy of 100 mJ passes the voltage through anode (2) and through the insulator/teflon (3) will form the plasma spot (10) on the cathode surface (4) via the surface discharge process at PGC (1) with a certain gas pressure. Then the plasma spots formed will be scattered by the plasma generator power supply (8) and the accelerated

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spot plasma scatter will ionize the gas in the plasma chamber cavity formed plasma arc discharge (11) around the hollow anode PGC area, and when both electrode systems are working in unison then the entire anode space will form a plasma arc discharge. By an accelerator voltage (9) electrons passing through the grid (5) will be accelerated until they are able to penetrate the foil window (6) which is further utilized for the irradiation of the sample (material).

To obtain a plasma spark from the ignitor electrode system then what is needed is how much voltage is mounted on the ignitor electrode system and its compatibility with the distance of the ignitor plasma electrode and the gas pressure inside the plasma chamber. After the plasma spark is obtained, it is known that the requirement of plasma arc discharging by arc discharge stress is present in plasma generator electrode. The plasma arc discharge on the plasma

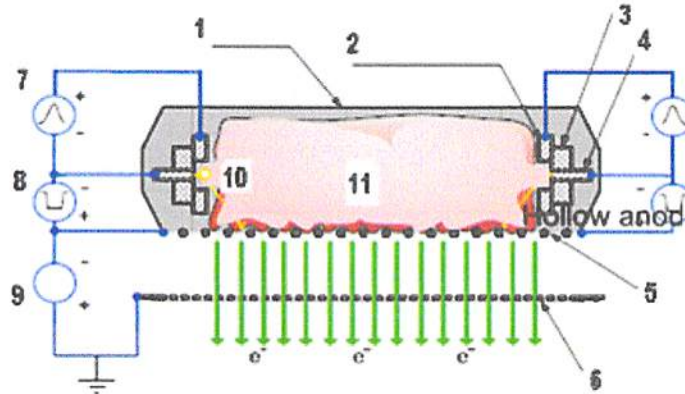


Figure 3. Schematic of the Pulse Electron Irradiator (PEI) system [12]: 1-Plasma Generator Chamber (PGC), 2-Ignitor electrode, 3-Isolator/Teflon, 4-Cathoda, 5-Grid, 6-Foil window, 7-Ignitor power supply, 8-Plasma generator power supply, 9-Accelerator high voltage, 10-Spot plasma, 11-Arc discharge plasma.

generator electrode shall meet the requirements of breaking determined by the voltage applied to the plasma generator electrode, the distance between the plasma generator anode and the ignitor electrode, as well as the gas pressure in the plasma generator [13]. The ignitor electrode attached to the right and left sides of the plasma generator electrode system is equipped with a system of Ignitor Discharge Power Supply (IDPS), which provides a 10 kV, 100 mJ power supply; and a plasma generator electrode connected to a system of Arc Discharge Power Supply (ADPS) that provides the voltage of 1 kV to produce the plasma arc discharges with current (5-10) A and pulse widths (10-100) μs in the PGC. Vacuum pumps are used to work on PGC and PEI chambers up to the order of 10^{-4} mbar, and external extractor high voltage up to a hundred of kV are enabled to accelerate and enlarge the electron power out of the grid system on the PGC wall toward the titanium (Ti) and then on target.

The electron-beam plasma fraction at the center of the open plasma area will be much larger (higher) than at the edges of the emission hole, this can be done by observing the plasma equipotential distribution in the electron extraction hole area on the PGC wall simulated (Opera program) on the basis of the use of potential surface data of 150 V by varying the magnitude of the high voltage extraction of V. PGC can be used Stainless Steel (SS) material of diameter $\Phi = 30$ cm and length of $l = 90$ cm, the electron extraction window (15×65) cm^2 along the side of the electron extraction window there are 15 pieces of grid holes with radius $r = 0.3$ mm respectively, the PEI chamber was made of SS in the form of a cylindrical with diameter of $\Phi = 70$ cm and length of $l = 130$ cm.

The first part of the report deals with the general situation of the country and the position of the various groups. It is a very interesting and well-written account of the country and its people. The author has done a great deal of research and has written a very interesting and well-written account of the country and its people.

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The seventh part of the report deals with the conclusion of the report. It is a very interesting and well-written account of the country and its people. The author has done a great deal of research and has written a very interesting and well-written account of the country and its people.

The simulation of electron beam extraction on the PEI from the plasma cathode electron source in order to produce a focused electron beam and having a trajectory of bearing close to the axis is done by stages : calculation in analytical /mathematically relation of electron beam current density (J_e) theory of density versus electron extraction voltage (V), and the geometry of the electron grid source system is continued simulated using the 3D opera program. The 3D opera program has also been used to design and simulate multi-beam electron sources on Klystron [14]. In the analytical calculation begins with the translation of the equation to obtain the relationship equation between the cathode-anode voltage (extracting voltage), the distance of the cathode-anode and extractable electron beam currents. The calculation of electron beam extraction voltage is carried out by the variation of the extraction voltage on the electron beam current with the fixed cathode distance taken (275 mm) that is adjusted to the PEI construction geometry. For the simulation begins by creating a geometry image of focussing or grid system of the electron source around the window, after the manufacture is continued simulating of the electron beam extraction. Extraction simulation was performed by variation of V extraction voltage of 5 kV, 10 kV, 20 kV, 30 kV and 100 kV.

RESULTS AND DISCUSSION

For the elucidation of the equations / relationships between electron V acceleration voltages to the density of the thermal electron beam J_{e0} flow to the x-axis can begin with the statement that the plasma boundary in the electron plasma diode will have much the same behavior as the ion extraction of extractor field change. The steady state position of the plasma electron emission surface that limits the area of the electric field E is determined by the conditions of the electrostatic field pressure equation and the kinetic pressure of the plasma gas electrons [15]:

$$\epsilon_0 \frac{E^2}{2} = n_e k T_e \quad (9)$$

This can mean the sheath thickness of the negative space l_e (the distance between the plasma electron emission limits to the collector = x) for the installation of the electron accelerating voltage V can be determined in the same way as for the relativistic speed plasma ion emissions ie

$$\left(\frac{4}{9}\right) \left(\frac{2e}{m_e}\right)^{1/2} \epsilon_0 V^{3/2} / x^2 = e n_0 (k T_e / 2\pi m_e)^{1/2} \quad (10)$$

Bearing in mind that for electrons to move at relativistic speeds then according to Boltzmann's law the speed is expressed as

$$v = (8 k T_e / \pi m_e)^{1/2} \quad (11)$$

substitution of equation (11) to the equation (10) we obtain equation:

$$\left(\frac{4}{9}\right) \left(\frac{2e}{m_e}\right)^{1/2} \epsilon_0 V^{3/2} / x^2 = \frac{1}{4} e n_0 v \quad (12)$$

Equation (12) is identical to the equation (1) or can be written as:

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$$\left(\frac{4}{9}\right)\left(\frac{2e}{m_e}\right)^{1/2} \epsilon_0 V^{3/2} / x^2 = j_{e0} \quad (13)$$

Equation (13) is the relationship between the electron acceleration voltage V on the density of the thermal electron beam current j_{e0} toward the x axis or by substitution $e/m_e = \eta$ can be written as:

$$V = f(x) = \left(\frac{9 j_{e0}}{4 \epsilon_0 (2\eta)^{1/2}}\right)^{2/3} x^{4/3} \quad (14)$$

Equation (14) which is identical with equation (8) in the theory chapter can be used to determine the extractor voltage V by using the Opera program.

Figure 4 shows the cross-sectional of potential space of PEI chamber with a diameter of $\Phi = 70$ cm and length of $l = 130$ cm. PGC cylindrical shape with diameter size $\Phi = 30$ cm and length $l = 90$ cm made of SS material inside PEI chamber with at the bottom made the electron extraction window of width (15×65) cm². Figure 5 shows a grid hole of 15 pieces on the lower PGC wall along the side of the electron extraction window (15×65) cm² with the radius size for each hole $r = 0.3$ mm. Thus in the extent of the electron extraction window there are 975 electron extraction holes[16].

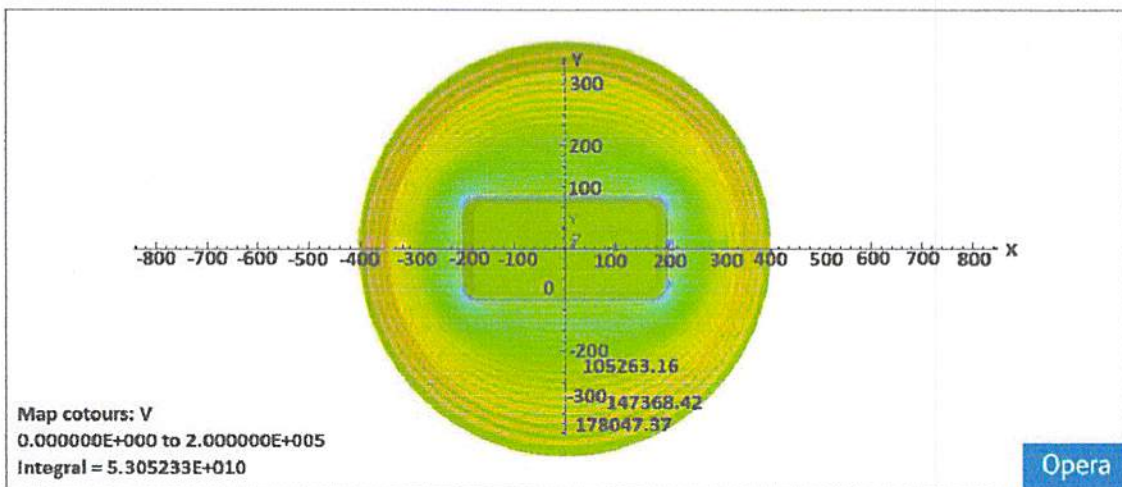


Figure 4. Cross-sectional of potential space of PGC chamber ($\Phi = 30$ cm, $l = 90$ cm) with the width of extraction window (15×65) cm² in the cylinder PEI chamber ($\Phi = 70$ cm, $l = 130$ cm).

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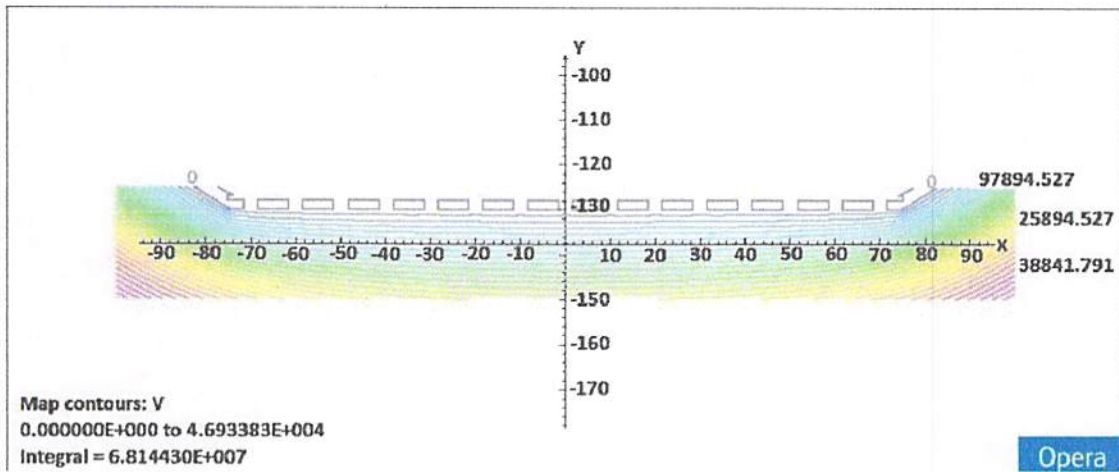
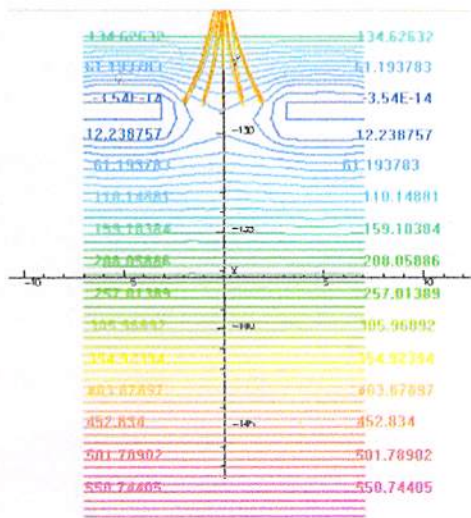


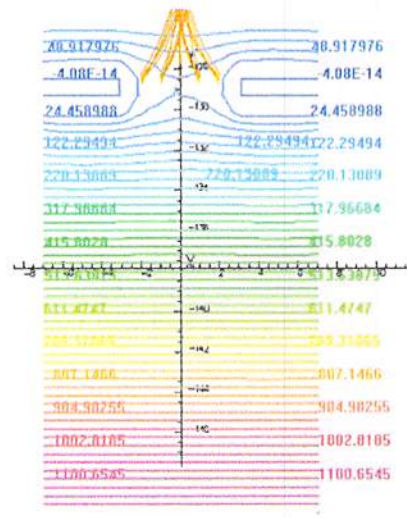
Figure 5. Grid hole as many as 15 pieces along the side of the window extraction area (15×65) cm^2 with radius size for each hole $r = 0.3$ mm.

The simulation results using the 3 D opera program for the electron beam extraction trajectory with its various extraction voltage of (5 kV, 10 kV, 20 kV, 30 kV, 100 kV) at a surface potential plasma of 150 V and an electrode (cathode-anode) distance of 275 mm is as shown in Figure 6.a. up to Figure 6.e.

The relationship between the extraction voltage V proportional to the beam current density j_e in equation (14) can be applied to both the ion source and the electron source. In the ion source application the amount of ions extracted corresponds to the number of ions available so that even the enhanced extraction voltage will not increase the ion beam currents. In contrast to the electron source, the electrons in PGC will always be available and multiplied by increasing the extraction voltage V . As shown in equation (1) that the electron electric current density j_e be exponentially increases with the extractor voltage increase (plasma potential difference of ϕ_p with extractor/collector potential ϕ_k) and the current density will be



5.a. Extraction trajectory of of plasma electron beam currents at 5 kV extraction voltage (no electron extraction yet).



5.b. Extraction trajectory of plasma electron beam currents at 10 kV extraction voltage (no electron extraction yet).

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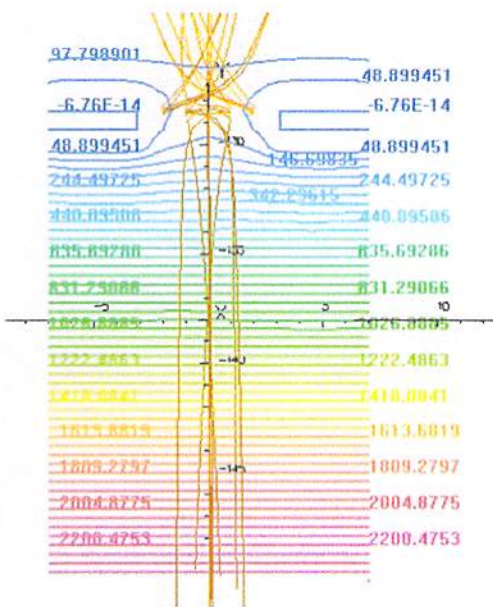
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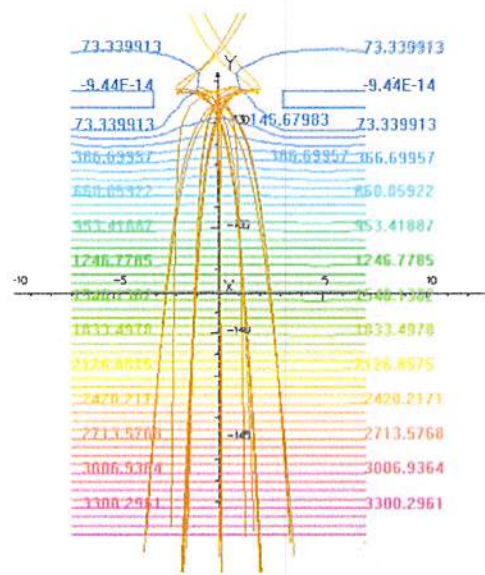
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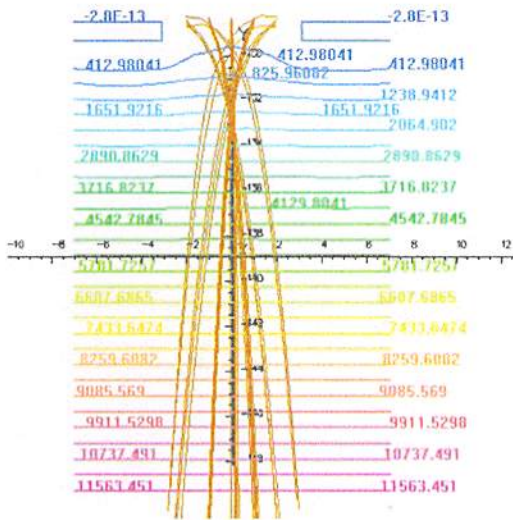
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6.c. Extraction trajectory of of plasma electron beam currents at 20 kV extraction voltage (electron beam extraction occurs).



6.d. Extraction trajectory of plasma electron beam currents at 30 kV extraction voltage (electron beam extraction occurs with increasing density of the beam)



6.e. Extraction trajectory of plasma electron beam currents at 100 kV extraction voltage (electron beam extraction occurs with the largest file density).

Figure 6. Extraction simulation results with its electron beam trajectory.

maximum when $\varphi_p = \varphi_k$ is the amount of thermal current density/saturated j_{e0} . For a further increase in V extraction voltage will not increase the electron extraction current but will only increase the magnitude of the energy. On the basis of the simulation results (Figs 6.a and 6.b) it is found that for the 5 kV and 10 kV extraction voltages, the electron beam has not been extracted. In this condition there is still a potential barrier so that the extraction of electrons from the plasma surface to the acceleration region has not occurred. It also means that the magnitude of the potential barrier is still equal to the power of the electron beam flow to the anode ($j_e = j_a$).

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In Figure 6.c the electron beam starts to appear extracted at the extraction voltage $V = 20$ kV, then in Figure 6.d when the extraction voltage $V = 30$ kV electron density of extracted beam is larger and finally in Figure 6.e for the extraction voltage of $V = 100$ kV the largest or closest density of electron beam density is obtained. From this it can be concluded that the calculation of analytical and simulation using 3D opera program obtained similarity that the higher the extraction voltage hence the higher density of electron beam currents are extracted and proved that at the extraction voltage of 100 kV then the density of electron beam obtained is the maximum/most dense compared to the smaller extraction voltage thereof.

CONCLUSION

The extraction of the electron beam on the PEI system in the area near the electron motion extraction hole is slowed by potential barriers, can be demonstrated from the use of a simulation (Opera program) with a plasma surface voltage of $V = 150$ volts on a variation value of extractor high voltage of 5 kV and 10 kV. The density of the electron beam current will appear larger in the simulation by mounting the higher extraction voltage i.e. at a voltage of $V = 20$ kV, 30 kV and 100 kV respectively.

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7. The seventh part of the document is a final note from the author, expressing their hope that the document will be helpful and informative. They also mention that they will continue to update the document as needed to reflect changes in the accounting profession.

- [12] WIDDI USADA, LELY SUSITA RM, AGUS PURWADI, Karakteristik Spot Plasma Pada Lucutan Busur Plasma, Prosiding Pertemuan dan Presentasi Ilmiah Penelitian Dasar Ilmu Pengetahuan dan Teknologi Nuklir, ISSN 0216-3128, PTAPB-BATAN Yogyakarta, 4 Juli 2012.
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The first part of the document is a letter from the Secretary of the State of New York to the Governor, dated January 1, 1912. The letter discusses the proposed amendments to the State Constitution, which were adopted by the people at a referendum on November 5, 1911. The Secretary notes that the amendments are designed to improve the government and to provide for a more efficient and economical administration. He also mentions that the amendments have been approved by the Governor and the Senate, and that they will take effect on January 1, 1912.

The second part of the document is a report from the State Board of Education, dated January 1, 1912. The report discusses the progress of the State Board during the year 1911. It notes that the Board has been successful in carrying out its duties and in improving the quality of education in the State. It also mentions that the Board has been successful in securing the passage of the proposed amendments to the State Constitution, which will provide for a more efficient and economical administration of the State.

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