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Calculation and Measurement of Electron Emission Current on Plasma Generator Tube for Pulse Electron Irradiator

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ABSTRACT

Calculation and measurement of electron emission current in Plasma Generaor Tube (PGT) especially for electron pulse irradiation has been done. After leaving the plasma surface through the emission window, electrons travel through the foil window on the vacuum chamber wall before entering the acceleration area. The extraction voltage U_a given to the plasma electron source device affects the current formation process I_e (electron extraction/emission beam energy) whereas the thermal electron emission current I_{e0}'s magnitude is influenced by the PGT's size. The shape and dimensions of the PGT that produces electron emission current have been determined using the size of the intended plasma arc discharge current for a specific plasma density. At an electron density of $n_e = 10^{17}$ m^{-3}, plasma temperature $T_e = 7$ eV, and arc discharge current $I_d = 80$ A (pulse width $\tau = 100$ µs), the measurements and computations show that the electron emission currents are 29.4 A and 29.8 A respectively, in the form of pulses. Because the current was alternating and in the form of pulses, it was able to enter the first cavity in the linear accelerator (Linac) experiment directly. As a result, it has passed through the grid and may be able to replace the electron buncher. On the PGT surface coated with a square SS grid/gauze, the emission window area measures (600×15) mm^2 with a grid radius of 0.3 mm and a grid distance of 0.25 mm. Apart from contributing to the plasma characteristics, the size of the grid holes also affects the electron emission current Ie. PGT grid holes are best shaped and sized as squares with side lengths of $p \approx 0.5$ mm. The electron emission current is influenced by the plasma properties as well as the grid hole size. The optimal size and shape of grid holes for the PGT are those with a grid radius of $r_e = 0.3$ mm.

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Introduction

Advances in accelerator technology are made possible by advances in beam physics, radio frequency (RF) sources, materials science, and fabrication techniques [1]. The electron plasma is emitted out into the accelerator area through a grid hole (extraction system) installed on the PGT wall. In the accelerator area the electron beam is accelerated to thermal speed by a Coulomb field using an external high voltage which is then extracted towards after passing through a foil window on the wall of the vacuum vessel.

The PGT is expected to produce a plasma arc discharge in the order of tens to hundreds of amperes (A), so the suitable discharge type is only an arc discharge type [2]. A system that is capable of producing electrons efficiently, the extraction is stable and the electron density distribution in the beam can be optimal is only by using an extraction system, namely by installing a grid as an emitter anode on the PGT wall [3]. The dimensions of the electron pulse irradiator and the extraction voltage must be adjusted to the size and shape of the PGT, because these parameter elements are of course very closely related to the conditions of whether or not electrons can be optimally extracted from the PGT.

The design activity for this electron extraction device began with the design of a PGT for a plasma arc discharge current $I_d = 80$ A (pulse width $\tau = 100$ µs) with a plasma/electron density in the range $n_e = 10^{10}$ cm^{-3}, where the optimum density value is in the range ne = (10^9-10^{12}) cm^{-3}. The determination of the discharge current parameters Id and ne electron density were chosen on the basis of the results of a literature study, initial coordination agreements that had been carried out in the PRTA- BRIN research subgroup, Yogyakarta. The purpose of this research is to design and build a PGT tool system that begins with the design/calculation which is then constructed by the PGT tool. From the results of the manufacture of this PGT tool, data on the electron emission current Ie (1-6) A can be presented at a plasma electron density of 10^{16} m^{-3} for various plasma electron temperatures between (1-11) eV or (1-11) 11600 °K. The amount of electron emission current that has passed through a grid of (0.3 - 1.0) mm is in the form of a pulse and is an alternating current that can function as a buncher in an electron linear accelerator (linac) tool as its main component. It has been previously known that the electron linac tool in addition to consisting of an electron source, buncher and accelerating cavity up to the requested power. The PGT tool can function as a buncher with the electron beam current that can directly enter the accelerator cavity which is only assisted by other auxiliary tool systems such as we know previously that linac typically consists of three main stage (1) emission of the

electrons from the cathode and their preacceleration with a DC field to the energy of tens of keV, (2) grouping the DC electron beam into bunches and their synchronization with the correct phase of high frquency electromagnetics field and (3) accelerating the banches of reltivistic electrons to the required energy [4]. The pulse electron irradiator devices are very promising for use in various industries, including in the health sector for the processing of toxic materials (natural rubber latex), surface modification in the semiconductor and polymer industries, and the food industry for pasteurization without damaging texture and nutrition, as well as for neutralization of waste [5,6].

Theory

The electron current density of the thermal plasma is

$$j_{e0} = en_e\sqrt{\frac{kT_e}{2\pi m}} \qquad (1)$$

with e = electron charge = 1.602 x 10^{-19} C, n_e = plasma density, k = Boltzmann constant = 1.381 × 10^{-23} J/K , Te = plasma temperature and m = electron mass = 9.109 × 10^{-31} kg.

For electron emission from plasma without extraction voltage Ua (Ua = 0)

When there is no extraction voltage ($U_a = 0$) or collector potential $\varphi_k = 0$, the electrons must be able to overcome the potential barrier, therefore the electron current density to the j_{ek} collector is given by the equation of Boltzmann relation:

$$j_{ek} = j_{e0}\exp\left(\frac{-e\varphi_p}{kT_e}\right) \qquad (2)$$

Shown to the equation (2) even though there is no extraction voltage ($U_a = 0$), there is still current flowing to the collector.

For the extraction U_a voltage is increased so that $0 < U_a < \varphi_p$ then the equation will be obtained:

$$j_{ek} = j_{e0}\, exp\left(\frac{-e(\varphi_p-\varphi_k)}{kT_e}\right) \qquad (3)$$

j_{ek} value in the equation (3) larger than the j_{ek} on the equation (2) namely when $U_a = 0$ or $\varphi_k = 0$. Because this can be said the equation in general, the current densitey of electron emission j_{ek} through a potential is determined by the Boltzmann relation [7]. If the j_{ek} value increases then the φ_p value also increases which will increase the potential barrier on the surface of the PGT wall and pass the electron plasma to other electrodes (which are not to the collector). Electron emission with extraction voltage ($0 < U_a < \varphi_p$) will experience an increase in plasma potential φ_p.

For the extraction voltage U_a equal to the plasma voltage φp ($U_a = \varphi_p$) then the equation is shown as follow:

$$j_{ek} = j_{e0}\,.1 = \frac{1}{4}\, e\ n_e\, v_e \qquad (4)$$

where $j_{e0} = j_{ek}$ is the electron current density of the thermal plasma as eq.(1) and $v_e = \sqrt{\frac{kT_e}{\pi m}}$

For electron emission with an extraction voltage $U_a > \varphi_p$,je size will still be obtained.

The electron emission current density je reaches a saturation value (maximum) with a much higher value than the initial electron emission current ($U_a = 0$) or can be expressed in the equation:

$$j_e = exp\left(\frac{-e\varphi_p}{kT_e}\right) \qquad (5)$$

It can be shown to the equation (6) i.e. the increasing factor of the electron emission current is

$$N = exp\left(\frac{e\varphi_p}{kT_e}\right) \qquad (6)$$

Thus, at the extraction voltage $U_a > 0$, for $U_a < \varphi_p$,$U_a = \varphi_p$ and $U_a > \varphi_p$ the value of je will be obtained which is the same as the value of je in equation (5), what is different is the magnitude of the beam energy which is proportional to the difference in the increase in the extraction stress.

To plan the value of the electron emission current in the IEP device, in addition to being determined by the magnitude of the extraction voltage Ua to increase the electron beam power, it is also necessary to know the use of the magnitude of the plasma density ne in the BGP to determine the magnitude of the thermal electron current. The magnitude of the plasma density ne depends on the dimensions (volume) and the magnitude of the plasma arc discharge current Id that occurs in the BGP, while the value of the arc discharge current Id depends on the operation of the trigger discharge voltage system and the arc discharge voltage system using the Ignitor Discharge Power Supply (IDPS) and Arc Discharge Power Supply (ADPS) tool. The plasma temperature parameter Te related to electron power is influenced by the magnitude of the extraction voltage U_a. Electron beam emission in the emission window or the formation of electron beams in the accelerator area will be optimal if the plasma density in the BGP is in the range of n_e = 109 cm^{-3} to n_e = 10^{12} cm^{-3} [8]. In a rectangular BGP with volume V (length p, width l and height t), if the plasma arc discharge current is I_d with a pulse width of τ, then the plasma density n_e, which is the amount of charge Q divided by the volume of the vessel V, is formulated as

$$n_e = \frac{Q}{V} = \frac{I_d\tau}{plt}(C\ cm^{-3}) = \frac{I_d\tau}{plte}(particle\ cm^{-3}) \qquad (7)$$

where e = electron charge = 1.602 x 10-19 C.

If the desired arc current pulse width τ = 100 μs and the base area of the BGP = ($p \times l$) = 80 cm × 20 cm = 1600 cm^2, then by substituting the quantities τ , p, and l in equation (7), the cylinder length t is obtained in the equation.

$$t = \frac{I_d\tau}{pln_e e}(cm) = 39.014\left(\frac{I_d}{n_e}\right)(cm) \qquad (8)$$

The plasma density n_e in a cylindrical BGP with radius r and length l is

$$n_e = \frac{Q}{V} = \frac{I_d\tau}{\pi r^2 l}(Ccm^{-3}) = \frac{I_d\tau}{\pi e r^2 l}(\text{particle } cm^{-3}) \qquad (9)$$

Or the cylinder radius r can be written in the equation.

$$r = \sqrt{\frac{I_d\tau}{\pi e n_e l}}\ \ (\text{cm}) \qquad (10)$$

If the desired arc discharge current in a cylindrical BGP is Id = 80 A with a pulse width τ = 100 μs, equation (10) can be written as

$$\mathrm{r} = 10^1\sqrt{\frac{1{,}5889}{\mathrm{n_e l}}}\,(\mathrm{cm}) \qquad (11)$$

Variations in the cylinder length r in equation (11) can be obtained i.e. with large variations in plasma density ne (in the range of 10^9 cm^{-3} to 10^{12} cm^{-3}) and the cylinder length l can be varied to obtain the value of the cylinder radius r at a certain plasma density n_e.

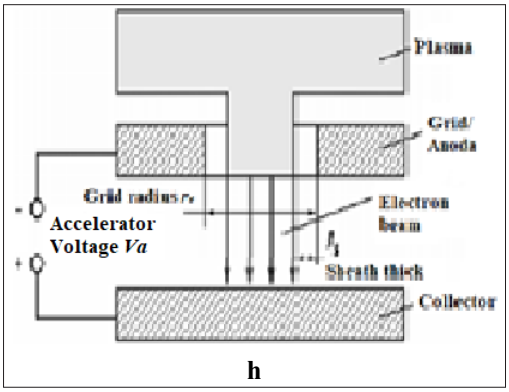
To determine the magnitude of the electron emission current through the grid with a certain emission current magnitude, this can be done by varying the size of the grid radius re and the value of the plasma parameters in PGT (electron density ne and electron temperature T_e). For plasma cathode electron source, using a total grid/emitter area of (15 × 600) mm^2, it is hoped that an optimum electron beam current I_e can be obtained, although of course it will also depend on the value of the electron emission efficiency α. Or in full for determination the emission electron current I_e according to the formula:

$$I_e = \alpha \times I(t) \qquad (12)$$

Where $I(t)$ is the total emission current passing through the grid and α is the electron emission efficiency which is usually formulated as:

$$\propto = \frac{S_e}{S_e + S_a} \quad \text{for } r_{e \ll l_s} \qquad (13)$$

In **Figure 1** is showed the schematic of electron emission/ extraction sheath stabilization namely how the electron beam is emitted from its surface through the grid radius r_e (as an anode) with a sheath thickness l_e, which is collected in the collector with an accelerating voltage of V_a:



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where S_e = total area of grid holes, Sa luas total lubang grid,
S_a = total area of anode l
r_e = grid radius,
l_s = sheath thickness.

The optimum alpha size is $\alpha_{opt.} = 0{,}50$ for $r_e \approx l_s$

If G = number of grid holes, then the electron extraction current is:

$$I_e = G\, A\, j_{e0} = G\, (\pi\, r_e^2)\, e\, n_e \sqrt{\frac{k\,T}{2\,\pi\,m}} \qquad (14)$$

The electron emission current Ie will be determined as a function of r_e, ne and T_e

Methodology

In a rectangular BGP with volume V (length p, width l and height t), if the plasma arc discharge current is Id with a pulse width of τ, then the plasma density n_e, which is the amount of charge Q divided by the volume of the vessel V, is formulated as in equation (7). And if the desired arc current pulse width τ = 100 μs and the base area of the BGP = (p×l) = 80 cm × 20 cm = 1600 cm2 then by substituting the quantities τ , p and l in equation (7) the cylinder length t will be obtained as in equation (8) while the plasma density ne in a cylindrical BGP with radius r and length l is as shown in equation (9) or the length of the cylinder radius r can be written in equation (10) and if in a cylindrical BGP the desired plasma arc discharge current is I_d = 80 A with a pulse width τ = 100 μs then equation (10) is written as equation (11) and the plasma density ne (in the range of 10^9 cm^{-3} to 10^{12} cm^{-3}) and the cylinder length l can be varied to obtain the value cylinder radius r at a certain plasma density n_e. To determine the electron emission current density through a grid area of A = (15 x 600) mm^2 is by using equation (12) to (14) in the theory chapter while the realization for the Pulse Elecron Irradiator (PEI) to be created/realized, the shape and output of the beam current can be adjusted according to the equations we use or can use the methodology that has been used in the results and analysis.

Results And Discussions

The Pulse Electron Irradiator (PEI) device which is a high vacuum chamber consists of a PGT and a high voltage electron extractor. The pulse electron irradiator device is as shown in Figure 2 [9]. The emitted electron beam is accelerated from the emission window (on the PGT wall) towards the foil window on the wall of the irradiator vessel The PGT where the plasma occurs of the trigger electrode, isolator, cathode, grid, trigger source, plasma generator consists of the components source, accelerating voltage, spot plasma, plasma and a foil window which is an pulse electron beam output.

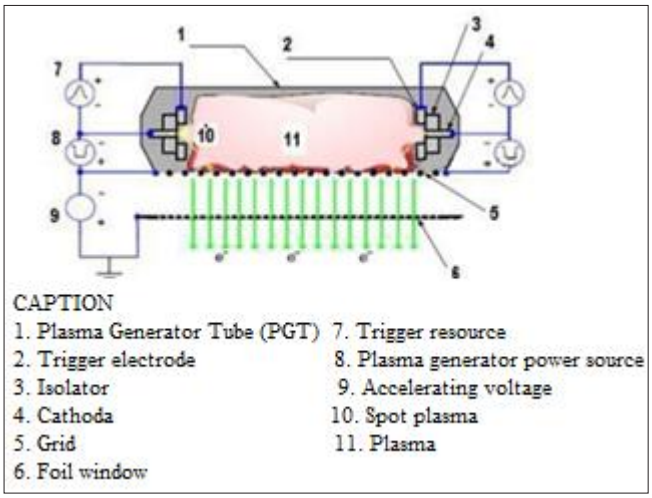

Figure 2: Simple Schematic of the Pulse Electron Irradiator [9].

The plasma electron source is inside the PGT so that the PGT is the most important vessel in the pulse electron irradiator device. The characteristics of the electron beam produced (output) of the PGT device are greatly influenced by the extraction voltage U_a and plasma parameters inside the PGT. The plasma inside the PGT as a whole is considered homogeneous and the electron energy distribution is Maxwellian. In the most specific situation, the plasma has a positive potential towards the discharge electrode and this means that ions are extracted from the plasma surface, while electrons must overcome a potential barrier to escape from the plasma surface to the collector electrode [10]. In the process of forming a plasma beam, a large increase in the extraction voltage must cause a large increase in the speed and energy of the ions and electrons. Application of extraction ion voltage will not change the conditions of ions emitted from the plasma into the acceleration area and also ion emission does not change the plasma parameters in the PGT. Therefore, the phenomenon of emission or injection of plasma electrons is not as simple as injection of the surface of the plasma.

Table 1 shows the calculation results for the variation in height (t) of a rectangular BGP (base area = p × l = 80 cm × 20 cm)

as a function of plasma density (n_e) and arc discharge current (I_d). The plasma density ne was varied within the optimum plasma density range in the electron source vessel, namely between $n_e = 10^9$ cm^{-3} to $n_e = 10^{12}$ cm^{-3}, while the plasma arc discharge current I_d was varied from $I_d = 30$ A to $I_d = 60$ A.

Table 1: Height t of a rectangular BGP (base area = p × l = 80 cm × 20 cm) as a function of plasma density (ne) and arc discharge current (Id) for a pulse width of $\tau = 100$ s. (ne varied from 10^9 cm^{-3} to 10^{12} cm^{-3} and I_d varied from 30 A to 60 A).

No.	Density $n_e \times 10^{10}$ cm^{-3}	High t (cm) for $I_d = 30$ A	High t (cm) for $I_d = 40$ A	High t (cm) for $I_d = 50$ A	High t (cm) for $I_d = 60$ A
1	0,1	11704,120	15605,490	19506,870	23408,240
2	0,2	5852,060	7802,747	9753,433	11704,120
3	0,3	3901,373	5201,831	6502,289	7802,747
4	0,4	2926,030	3901,373	4876,717	5852,060
5	0,5	2340,824	3121,099	3901,373	4681,648
6	0,6	1950,687	2600,916	3251,144	3901,373
7	0,7	1672,017	2229,356	2786,695	3344,034
8	0,8	1463,015	1950,687	2438,358	2926,030
9	0,9	1300,458	1733,944	2167,430	2600,916
10	1	1170,412	1560,549	1950,687	2340,824
11	2	585,206	780,275	975,343	1170,412
12	3	390,137	520,183	650,229	780,275
13	4	292,603	390,137	487,672	585,206
14	5	234,082	312,111	390,137	468,165
15	6	195,069	260,092	325,114	390,137
16	7	167,202	222,936	278,669	334,403
17	8	146,301	195,069	243,836	292,603
18	9	130,046	173,394	216,743	260,092
19	10	117,041	156,055	195,069	234,082
20	20	58,521	78,0275	97,5343	117,041
21	30	39,014	52,018	65,023	78,027
22	40	29,2603	39,014	48,767	58,521
23	50	23,408	31,211	39,014	46,816
24	60	19,507	26,009	32,511	39,014
25	70	16,720	22,293	27,867	33,440
26	75	15,605	20,807	26,009	31,211
27	76	15,400	20,533	25,667	30,800
28	77	15,200	20,267	25,333	30,400
29	78	15,005	20,007	25,009	30,010
30	79	14,815	19,754	24,692	29,631
31	80	14,630	19,507	24,383	29,260
32	90	13,004	17,339	21,674	26,009
33	100	11,704	15,605	19,507	23,408

For a cylindrical BGP with radius r and length l, the plasma density n_e is determined by equation (9) and the determination of the cylinder radius r uses equation (10). Because the desired plasma arc discharge current is $I_d = 80$ A with a pulse width $\tau = 100$ μs, if the plasma density n_e is the same as the ne that occurs in a rectangular BGP and using equation (11), the radius r of the BGP (cylindrical shape) that must be used for a certain cylinder length l can be determined. Table 2 shows the results of calculating the value of the cylinder radius r for a cylindrical BGP (plasma arc discharge current $I_d = 80$ A, pulse width $t = 100$ μs) as a function of the plasma density n_e and the cylinder length l (the plasma density n_e is varied from $n_e = 10^9$ cm^{-3} to $n_e = 10^{12}$ cm^{-3} and the cylinder length l is varied from 60 cm to 90 cm).

Table 2: Radius *r* of Cylindrical BGP (for Plasma arc Discharge current I_d = 80A, t = 100μs) as a Function of Plasma Density n_e and Cylinder Length l (n_e varied from 10^9cm^{-3} to 10^{12} cm^{-3} and l varied from 60 cm to 90cm).

No.	Density $n_e \times 10^{10}$ cm^{-3}	Radius r (cm) for l = 60 cm	Radius r (cm) for l = 70 cm	Radius r (cm) for l = 80 cm	Radius r (cm) for l = 90 cm
1	0,1	514,6034	476,4302	445,6596	420,1719
2	0,2	363,8796	336,887	315,1289	297,1064
3	0,3	297,1064	275,0671	257,3017	242,5864
4	0,4	257,3017	238,2151	222,8298	210,086
5	0,5	230,1376	213,0661	199,305	187,9066
6	0,6	210,086	194,5018	181,9398	171,5345
7	0,7	194,5018	180,0737	168,4435	158,8101
8	0,8	181,9398	168,4435	157,5645	148,5532
9	0,9	171,5345	158,8101	148,5532	140,0573
10	1	162,7319	150,6605	140,9299	132,87
11	2	115,0688	106,533	99,65252	93,9533
12	3	93,9533	86,98385	81,36594	76,71255
13	4	81,36594	75,33023	70,46497	66,43501
14	5	72,77591	67,3774	63,02579	59,42128
15	6	66,43501	61,50687	57,53441	54,24396
16	7	61,50687	56,9443	53,26651	50,22015
17	8	57,53441	53,26651	49,82626	46,97665
18	9	54,24396	50,22015	46,97665	44,29001
19	10	51,46034	47,64302	44,56596	42,01719
20	20	36,38796	33,6887	31,51289	29,71064
21	30	29,71064	27,50671	25,73017	24,25864
22	40	25,73017	23,82151	22,28298	21,0086
23	50	23,01376	21,30661	19,9305	18,79066
24	60	21,0086	19,45018	18,193978	17,15345
25	70	19,45018	18,00737	16,84435	15,88101
30	75	18,79066	17,39677	16,273189	15,34251
31	76	18,66663	17,28194	16,165774	15,24124
32	77	18,54502	17,16935	16,060458	15,14195
33	78	18,42576	17,05894	15,957174	15,04457
34	79	18,30877	16,95063	15,855858	14,94905
35	80	18,19398	16,84435	15,756447	14,85532

36	90	17,15345	15,88101	14,855321	14,00573
37	100	16,27319	15,06605	14,092995	13,287

Table 3 shows the results of calculating the number of grid holes in the emission anode area A = (15 × 600) mm^2 against variations in grid hole radius r_e with a distance between grid holes h = 0.25 mm.

Table 4 shows the calculation results of the electron emission current (I_e) as a function of grid radius (0.28 mm to 0.90 mm) at a plasma electron density of $n_e = 10^{17}$ m^{-3} for various electron temperature values T_e = (1 eV to 5 eV), and continued in Table 5 for T_e = (6 eV to 10 eV).

Table 3: Calculation Results of the Number of Grid holes in the Emission anode area A= 15 × 600 mm^2 with Respect to Variations in Grid hole Radius r_e with a Distance between Grid Holes h = 0.25 mm.

Number of grid holes (at emission anode A = 15 × 600 mm^2 against variation of grid hole radius r_e with distance between grid holes h = 0.25 mm				
No	Grid radius r_e (mm)	Square side s = $(\pi r_e^2)^{1/2}$	The media area of each grid L = (s + h)^2	Number of grid holes n = A/L
1	0.28	0.49616	0.55675	16165
2	0.30	0.53160	0.61090	14732
3	0.40	0.70880	0.91930	9790
4	0.50	0.88600	1.29050	6974
5	0.60	1.06320	1.72450	5219
6	0.70	1.24040	2.22130	4052
7	0.80	1.41760	2.78090	3236
8	0.90	1.59480	3.40330	2644

Table 4: Value of Electron Emission Current (I_e) as a Function of Hole Radius r_e ($n_e = 10^{17}$m^{-3}) for Electron Temperature T_e = (1, 2, 3, 4, 5) eV.

Plasma Electron Temperature T_e (oK) / Electron Emission Current						
Grid radius (m)	**Number of gride holes**	**1×11600/ I_e (A)**	**2×11600 / I_e (A)**	**3×11600 / I_e (A)**	**4×11600/ I_e (A)**	**5×11600 / I_e (A)**
2.80E-04	16165	1.06E+01	1.50E+01	1.84E+01	2.12E+01	2.37E+01
3.00E-04	14732	1.11E+01	1.57E+01	1.92E+01	2.22E+01	2.48E+01
4.00E-04	9790	1.31E+01	1.85E+01	2.27E+01	2.62E+01	2.93E+01
5.00E-04	6974	1.46E+01	2.06E+01	2.53E+01	2.92E+01	3.26E+01
6.00E-04	5219	1.57E+01	2.22E+01	2.72E+01	3.15E+01	3.52E+01
7.00E-04	4052	1.66E+01	2.35E+01	2.88E+01	3.32E+01	3.72E+01
8.00E-04	3236	1.73E+01	2.45E+01	3.00E+01	3.47E+01	3.88E+01
9.00E-04	2644	1.79E+01	2.54E+01	3.11E+01	3.59E+01	4.01E+01

Table 5: Value of Electron Emission Current (I_e) as a Function of Hole Radius r_e (n_e=10^{17}m^{-3}) for Electron Temperature T_e = (6, 7, 8, 9, 10) eV.

Plasma Electron Temperature Te (oK) / Electron mission Current						
Grid radius (m)	**Number of gride holes**	**6×11600/ I_e (A)**	**7×11600 /I_e (A)**	**8×11600 / I_e (A)**	**9×11600/ I_e (A)**	**10×11600 / I_e (A)**
2.80E-04	1.615	2.60E+01	2.81E+01	3.00E+01	3.18E+01	3.36E+01
3.00E-04	14732	2.72E+01	2.94E+01	3.14E+01	3.33E+01	3.51E+01
4.00E-04	9790	3.21E+01	3.47E+01	3.71E+01	3.93E+01	4.15E+01
5.00E-04	6974	3.58E+01	3.86E+01	4.13E+01	4.38E+01	4.62E+01
6.00E-04	5219	3.85E+01	4.16E+01	4.45E+01	4.72E+01	4.97E+01
7.00E-04	4052	4.07E+01	4.40E+01	4.70E+01	4.99E+01	5.26E+01
8.00E-04	3236	4.25E+01	4.59E+01	4.91E+01	5.20E+01	5.48E+01
9.00E-04	2644	4.39E+01	4.75E+01	5.07E+01	5.38E+01	5.67E+01

From the experimental results it can be shown that there are two discharges that occur sequentially in the PGT, namely the plasma spot discharge and the arc discharge. The plasma spot in the PGT which functions as an arc discharge trigger occurs at a location 1 mm in front of the ignitor electrode surface which is diluted by a 12 kV IDPS voltage power source with an argon working gas pressure of the order of 10^{-4} mBar. Mean while, arc discharge plasma appears due to the potential difference between the surface of the plasma spot volume and the potential of the wall of the PGT which is installed with a 1 kV ADPS voltage power source. Photo images of the arc discharge plasma and the electron beam emission current coming out of the beam window on the wall of the PGT are shown in Figure 3.

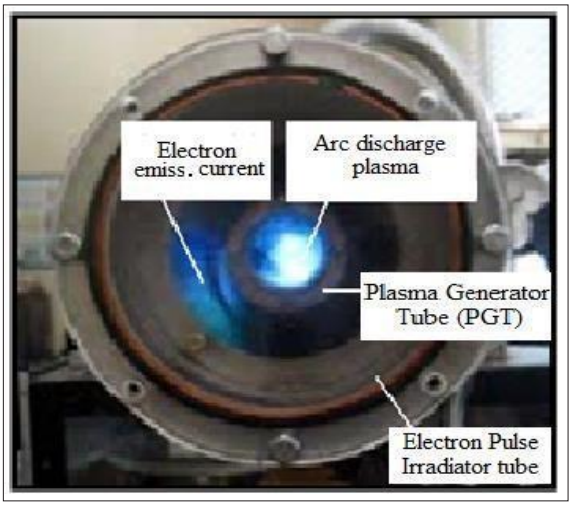

Figure 3: Photograph of arc Discharge Plasma in the PGT.

In Figure 4 is shown a photo image of a partial cross-section of the electron emission current beam coming out of a beam window of (15 × 600) mm^2 (on the wall of the PGT) which is observed through the beam window on the wall of the MBE vessel. The magnitude of the plasma arc current which is the electron current discharge I_e in the PGT is measured using a Rogowski coil and an oscilloscope.

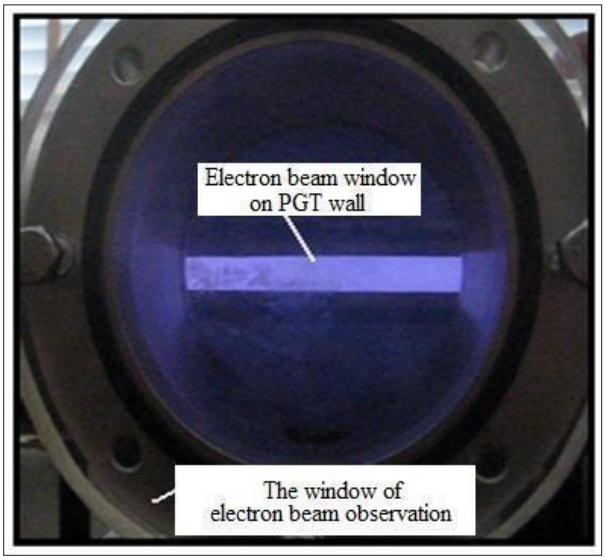

Figure 4: Cross-Sectional Photo of the Electron Emission Current Beam Coming out of PGT.

The plasma electron emission current I_e in the PGT is formed by the potential difference between the surface potential of the plasma volume φ_p (plasma is formed due to the high voltage of Ignitor discharge power suppy in the trigger electrode system) and the positive electrode potential on the wall of the plasma generator φ_c (which functions as a collector). In the experiment, the plasma potential value φ_p is greater than the potential of the collector/ wall of the of the PGT (Ignitor discharge power supply voltage ~ 12 kV, Arc discharge power supply voltage ~ 1 kV).

The grid is planned to be installed on the PGT wall which functions as a plasma emitter that extracts electrons currents from the PGT in the form of pulse. The PGT is covered with a grid made of SS material in a square shape with an optimum hole size of (15 × 600) mm^2. If the distance between one grid hole and another is 0.25 mm, then for a PGT emitter media/area of (0.75 × 0.75) mm^2 there will be 1 grid hole, as shown in **Figure 5.**

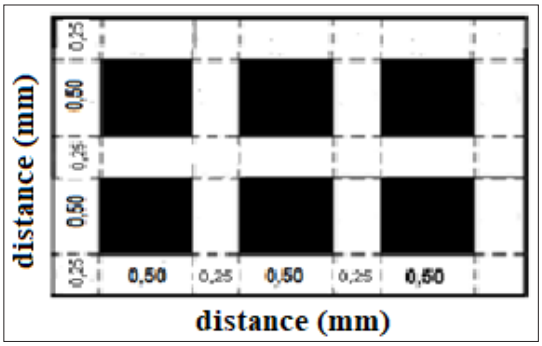

Figure 5: Grid holes (0.50×0.50) mm^2 with Distance Between Grid Holes one to the Other is 0.25 mm.

The maximum electron emission current Ie through the grid hole is the result of multiplying the maximum electron emission current density in equation (4) with the area of the grid hole, so the size of I_e will also depend on plasma parameters such as electron density ne, electron temperature T_e also depends on size. grid grid r_e. Meanwhile, the other quantities in this equation are just constants whose values are certain, namely for e = electron charge = 1.602 × 10^{-19} C, k = Boltzmann's constant = 1.37 × 10^{-23} J/K and me = electron mass = 9,11 ×10^{-31} kg. Because the number of grid holes is known and the magnitude of the electron emission current Ie through each grid hole is also calculated, the total electron emission current exiting through the electron emitter on the PGT can be determined.

A square grid measuring (15 × 600) mm^2 is identical to a circular grid with a radius of 0.28 mm or 2.8×10^{-4} m because the area of both geometric shapes has the same value. Furthermore, this can be used as a standard that each grid hole is circular with a radius of 0.28 mm × 0.30 mm is the optimum grid hole radius size.

Because the optimum grid hole radius (circular shape) for plasma cathode electron source is 0.30 mm and the distance between adjacent grids is 0.25 mm, for an emitter surface area of (0.85 × 0.85) mm^2 will be occupied by 1 (one) hole grid.

According to theory, the electron extraction efficiency will apply to a grid hole radius (r_e) that is much smaller than the plasma sheath thickness (l_e) and the optimum value is $\alpha_{opt.}$ = 0.50. This may be interpreted that the efficiency value α is in the range (0 – 50) %. The extraction electron efficiency (α) at the extraction voltage (maximum) that will be obtained is $\alpha = I_e/I_d$ = 29.80 A / 80 A =

37.25 %. Furthermore, it can be seen from the table (calculation results), the magnitude of the electron beam emission current I_e, whose value is close to 29.80 A, is I_e = 29.40 A, so that the size of the grid hole and the corresponding plasma parameters and or the best one to use in the electron irradiator device is a square shape with a side length of p = 0.53 mm or p close to 0.50 (p ≈ 0.50 is a common size on the market) and the plasma parameters in PGT use an electron density of ne=10^{16} m^{-3} and the plasma electron temperatur T_e=7 eV.

In **Figure 6** and **Figure 7** the graph of the electron emission current Ie is shown as a function of grid radius re but in the previous table but now with a density ne = 10^{16} m^{-3}) for the temperature T_e= (1 to 6) eV and Te=(6 to 11) eV.

If compared with what other people have done by R. Purwadi, et al [11], namely in **Figure 8** the design of this pulse electron source equipment is very different with **Figure 2**, namely without using a pressure vessel, which will be cheaper and simpler. Therefore, to plan the value of the electron extraction current on the PGT

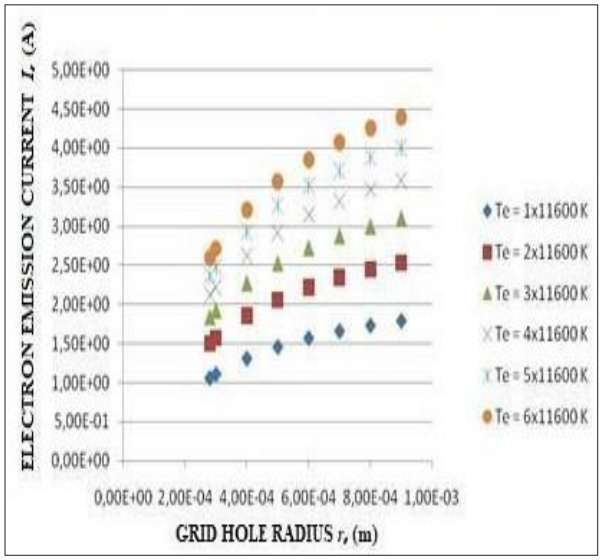

Figure 6: Electron Emission Current Graph I_e Function of Grid Radius r_e at Electron density n_e = 10^{16} m^{-3} for temperature Te = (1-6) eV.

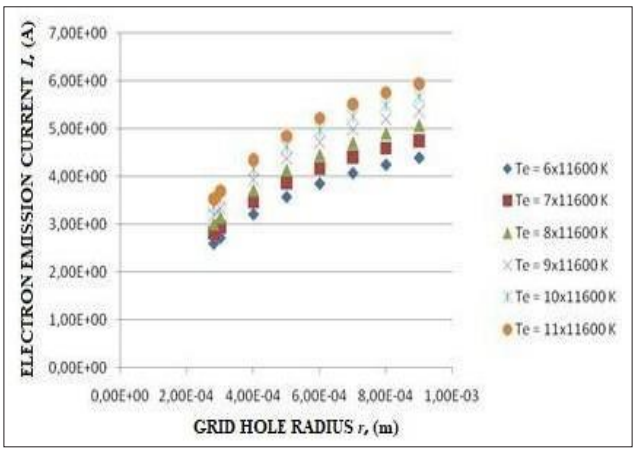

Figure 7: Graph of Electron Emission Current I_e as a Function Of Grid Radius re on Density Electron n_e = 1016 m^{-3} for Temperature T_e.= (6-11) eV.

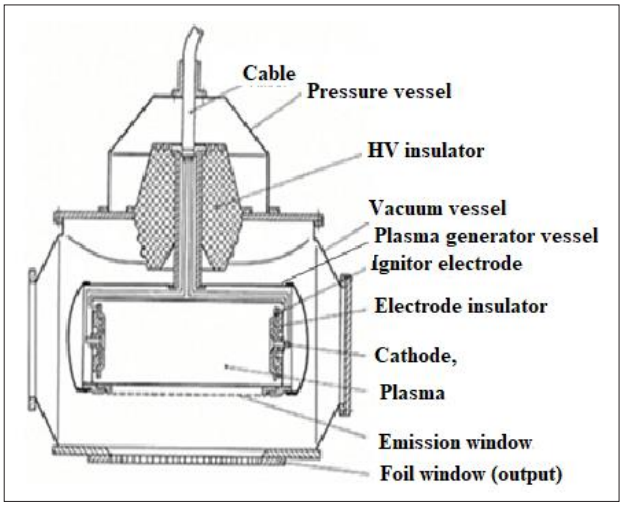

Figure 8: Simple Schematic of the Pulsed Electron Source device [11].

device, besides being determined by the extraction voltage U_a, to increase the power of the electron beam. It's like other people have done that pulse electron irradiator equipment can produce wide electron beams up to about 1 meter in diameter, electron beam currents can be from microampere to kiloamperes, beam current density is up to about 100 A/cm^2, pulse duration is from nanosecond to second, and electron energy is from a few keV to hundreds keV.

The system that is able to produce efficient electrons, stable extraction, and optimum distribution of electron density in the beam is only by using an extraction system by installing a grid as an emitter anode on the PGT wall. The emission window on the PGT is covered with a square grid sheet (cassette) made of Stainless Steel (SS) with an optimum hole size. If the distance between one grid hole and another is known then for a certain area of PGT emitter media/area there will be 1 grid hole. The maximum electron emission current Ie through the grid hole is the result of multiplying the maximum electron emission current density in equation (4) with the area of the grid hole. The magnitude of Ie besides depending on plasma parameters such as the electron density ne, the temperature of the electrons Te also depends on the size of the re grid radius. Since the number of grid holes is known and the magnitude of the electron emission current Ie through each grid hole can be calculated, the total electron emission current flowing out through the electron emitter in the PGT can be determined.

Conclusion

Plasma density ne depends on the dimensions (volume) of the PGT or linear accelerator (linac) electron buncher and the magnitude of the plasma arc discharge current Id and the pulse width τ that occurs in the PGT, while the values of I_d and τ depend on the operation/setting of the trigger power source system and the plasma arc discharge power source. Based on the calculation and measurement results, it can be concluded that for the use of I_d = 80 A with τ = 100 μs and the area of the electron beam emission hole (600 × 15) cm^2, the dimensions of the PGT are rectangular with dimensions (80×20×40) cm^3. From the calculation and measurement results, the electron emission currents were obtained respectively of 29.4 A and 29.8 A in the form of pulses that occurred at an electron density of ne=10^{17} m^{-3}, plasma temperature T_e = 7 eV, arc discharge current I_d = 80 A (pulse width τ = 100 μs), where the current obtained has

passed through the grid and has been able to replace the function of the electron buncher because the current has been alternating and in the form of pulses so that it can directly enter the initial cavity in the linear accelerator (Linac) experiment. The size of the rectangular PGT with a volume of 0.064 m^3, an emission window area of $(600\times15)\times10^{-6}$ m^2, a grid radius of 3×10^{-4} m (on the PGT surface coated with a square SS grid/gauze with a grid distance of 0.25×10^{-3} m). The magnitude of the electron emission current Ie depends not only on the plasma parameters but also on the size of the grid holes. The optimum shape and size of the PGT grid holes are square with side length $p \approx 5\times10^{-4}$ m. The value of electron emission efficiency (α) at injector voltage V = 3 kV is obtained as α = 37.25%. The magnitude of the electron emission current Ie depends not only on plasma parameters but also on the size of the grid holes, where the optimum shape and size of the PGT are grid holes with a grid radius of $re = 3\times10^{-4}$ m.

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