Functional test of electron beam extraction for pulse electron irradiator

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Abstract. Function test of electron beam extraction for pulse electron. The functional test of pulse electron beam extraction has been performed. The purpose of the functional test is to know the magnitude of the current and the distribution of the extracted electron beam. The plasma current detection system consists of three Rogowski coils mounted on output cables of Ignitor Discharge Power Supply (IDPS), Arc Discharge Power Supply (ADPS) and Faraday Cup (FC), while the voltage and pulse width are observed using an Oscilloscope. From the measurement results obtained that the spot and plasma currents are 11,24 A and 119,65 A. At the extraction voltage of 3 kV obtained the maximum extraction current are 13,1 A and 6,7 A for the position of FC near the ignitor electrode and in the middle of the grid respectively. It can be concluded that the pulse electron beam can be extracted by the distribution of the beam near the ignitor electrode higher than in the middle position of the grid.

1. Introduction

The electron accelerator machine often called the Electron Beam Machine (EBM) is a new type of technology that has been developed in the past four decades as a source of radiation in the irradiation process of industrial and agricultural products. The use of EBM in industry has developed rapidly in developed countries, especially in the process of drying the surface curing of coatings, the process of forming cross-bonds in plastics, rubber and cable insulation materials, natural rubber vulcanization processes, sterilization of medical equipment, food preservation, textile modification and graft polymerization [1,2,3,4]. When compared with conventional thermal processes or chemical processes, the electron irradiation process has several advantages including: producing a higher quality product, does not cause pollution to the environment, saving energy, reactions occur at room temperature, the process that occurs is easily controlled, lower operating costs for mass production. For the vulcanization of natural rubber latex, crosslinking is the most dominant reaction that occurs during the electron irradiation process. Physical properties of natural rubber latex will change with the formation of crosslinking, for example increased resistance to solvents, increasing the tensile strength and hardness, elongation and a reduced level of heat resistance (thermal deformation) [3,4,5]. To increase the homogeneity of the irradiation beam and ease of operation, the type of EBM is also developing, one of which is the pulse EBM. EBM pulses based on plasma cathode electron source will produce a higher beam current compared to EBM with a thermionic emission electron source.

In its development the application of the pulsed electron beam is quite extensive as in the industrial field, the EBM pulse can be used in the latex industry, surface modification in the semiconductor and polymer industries, and the food industry for pasteurization without damaging the texture and nutrition,
as well as the neutralization of waste [6,7,8]. The pulse EBM component consists of an electron source vessel that is equipped with a plasma emitter system, plasma power source, accelerator voltage and a vacuum system. Plasma emitter is a plasma vessel equipped with a grid, two pairs of electrode systems, feedthrough plasma power supplies and accelerator electrode systems [9]. Each electrode system unit has 3 electrode components, namely the cathode (Mg), the anode ignitor (SS 304) and the plasma generator anode (SS 304), and the insulating between the cathode and the ignitor anode nylon PA6. To generate plasma, plasma power supplies consist of Ignition Discharge Power Supply (IDPS) and Arc Discharge Power Supply (ADPS). Plasma sparks are formed between the cathode and the ignitor anode which are given IDPS voltage which corresponds to the distance of the ignitor electrode and the gas pressure in the plasma vessel resulting in surface discharge. After the plasma spark is obtained, then the plasma is dissipated to all plasma vessels by the ADPS voltage attached to the plasma generator electrode with the requirements to meet the voltage specified by the plasma generator electrode and the distance between the scatter voltage and the electrode ignitor [10,11,12].

In the electron beam extraction function test begins with the formation of a plasma spot on the ignitor electrode with an IDPS voltage of about 10 kV pulse width of 35 µs, then the formation of a plasma arc in a plasma generator vessel with a voltage of about 1 kV pulse width of 100 µs, followed by channeling the extraction voltage 1000 V to 3000 V and electron beam extracted through the emission grid. The magnitude of the electron beam current is observed using the Rogowski coil which is a closed coil around the detected electron beam current axis, as an inductor with a toroidal shaped ferrite core will capture the induced magnetic field from the electric current flow and the induced magnetic field will provide voltage after passing through a passive RC integrator. In addition, measurements of electron beams using the Faraday Cup are installed in front of the emission grid for various positions. The expected results of the electron beam extraction function test are to find out the large electron current extracted and the electron beam current distribution for various positions so that the optimum beam is obtained which will be used as an electron source for pulse EBM.

2. Basic Theory

In general, plasma electron sources consist of two parts. The first part is the plasma generator which provides ion production and thus functions as a plasma electron reservoir. The second part is the extraction system which functions to extract electrons from the electron source. The two parts can be treated independently as long as the plasma generator provides electrons at the required current density and covers the entire extraction system area.

Plasma generators determine plasma emission parameters, such as plasma density or electron temperature, but the extraction system determines the beam’s current parameters and beam quality. For solid-state cathodes such as the thermionic hot filament cathode, the electron beam can be extracted properly depending on the space charge condition or emission capability. The electron emission current density can be calculated using Child-Langmuir's law. In this case the emission region is assumed to be planar and infinite, with the ion having zero initial energy in the longitudinal direction (z-direction).

\[ j_e = \frac{4}{9} \varepsilon_0 \sqrt{\frac{2e}{m}} \frac{1}{d^2} U_{ACC} \frac{1}{\gamma} \]

(1)

where \( \varepsilon_0 \) is the vacuum permittivity, \( e \) electric charge, \( m \) the electron mass, \( d \) gap width, and \( U_{ACC} \) decrease potential. The total file flow \( I_e \) can be calculated using the equation:

\[ I_e = \frac{4}{9} \pi r^2 \varepsilon_0 \sqrt{\frac{2e}{m}} \frac{1}{d^2} U_{ACC} \frac{1}{\gamma} \]

(2)

From the formulation of the above, the amount of electron beam current \( I_e \) depends on the electron emission current density plasma generator and the magnitude of the voltage extraction. The equilibrium current density of electrons, electron temperature, the area of the aperture of the grid and the magnitude of the extraction voltage can be done by calculation using equation 3.
The amount of extracted current loss is influenced by various geometries of the system grid including the comparison of the area of the aperture and the fins grid. In this study measurements of electron beam current flowing out of the grid plasma generator, and for the transformation of the electron beam to atmospheric pressure, the grounding mesh is replaced by a foil thin metal. At that time the electron beam current loss in the foil depends on the electron energy, material and thickness of the foil.

Measurement of the output voltage of the plasma spot forming ignitor power source uses a voltage divider probe, where the voltage measurement results are lowered 1000 times by using a 50 MΩ/50 kΩ voltage divider resistor, while the plasma spot current can be determined using the Rogowski coil. Rogowski's coil has the principle of working to capture a magnetic field in the space around a conductor with current flowing. The coil output voltage is formulated as the rate of change of the magnetic flux [13,14].

$$\frac{1}{4}\varepsilon n e \sqrt{\frac{8kT}{am}} = \frac{4}{9}\pi r^2 e \sqrt{\frac{2e}{m}} \frac{1}{d^2} U_{dc} \frac{1}{2}$$

Figure 1. Electron beam extraction experiment scheme.

Thus it can be seen that the Rogowski coil output voltage depends on the magnitude of the change in current per unit time, number of turns, surface area of the coil and distance from the current axis. It is seen in equation (4) that the coil output voltage is proportional to the change in current, so to determine the amount of current I(t) the coil output voltage must be integrated. In the experiment, the coil output voltage is subject to the integrator circuit RC on the coil, so the magnitude of the current can be determined according to the equation:

$$I(t) = \frac{2\pi r RC}{\mu n A} V(t)$$

where I(t) : plasma spot current, R : integrator resistance, C : integrator capacitance, V (t) : measured voltage. The experiment scheme is shown in Figure 1.
3. Methodology

Doing the formation of spots plasma through electrode ignitor voltage IDPS, and spot plasma dissipated into the plasma arc meets the vessel plasma using electrodes plasma generator with a voltage ADPS, Then proceed to extract electrons present in the plasma comes out through the grid hole which is attached to the bottom of the plasma generator electrode. Extraction voltage varies from 1000 V to 3000 V because the electrode isolator is only able to withstand a maximum voltage of 3500 V and the electron beam is measured using a Faraday cup mounted in front of the grid with various positions, then the amount of extracted electron current is measured through the Rogowski coil output mounted on Faraday Cup.

4. Results and Discussion

The formation of plasma arcs is preceded by the presence of plasma spots, while the formation of plasma spots and arcs is characterized by signals detected using the Rogowski coil. In Figure 2 can be seen the measured voltage is Rogowski coil on IDPS (top) and ADPS (bottom), in the graph of measured voltage of about 2.04 Volts with a pulse width of 37 µs. Using equation 5 and taking into account the specifications of the components installed in the Rogowski coil integrator circuit, a current spot plasma of 11.24 A. is also seen. The measured voltage of the Rogowski coil on the ADPS (below) is about 5.8 Volts with a pulse width of 97 us , so from the calculation results obtained plasma arc current is 119.65 A.

The amount of extracted current is strongly influenced by the density of the plasma formed in the plasma generator, the size of the hole grid and the extraction voltage applied. In the state of the parameters of a balanced plasma match with the extraction voltage, the extracted electron beam will be obtained which is parallel/perpendicular to the surface of the grid. By varying the extraction voltage, several measurements of the extracted electron beam current are obtained, the result is shown in Figure 3 up to Figure 5.

Figure 3 can be seen as the measured voltage of the Rogowski coil at the left edge by varying the extraction voltage from 1 kV to 3 kV with an increase of 0.5 kV. At the extraction voltage of 1 kV to 3 kV, the total electron beam current is 25 A; 41.7 A; 56.9 A; 71.5 A and 83.5 A, while in Faraday Cup is 5.9 A; 8.3 A; 10.7 A; 11.9 A and 13.1 A. From the measurement results above for the total electron beam is always greater than the Faraday Cup, this is caused by the electrons are drawn/extracted are the width of the hole grid (1.5 × 60 cm²) attached, while the Rogowski coil in Faraday Cup only measures the beam of the area Faraday Cup with a cross-section (1.5 × 8 cm²).
Figure 4 shows the magnitude of the electron beam extracted current as a function of the extraction voltage at the FC center position of the grid. At the extraction voltage of 1 kV to 3 kV, the total electron beam current is obtained 14.3 A; 26.2 A; 40.5 A; 50 A and 71.5 A while the Faraday Cup is 3 A; 4.8 A; 6 A; 6.6 A and 6.7 A. In Figure 5 can be seen the measured voltage of Rogowski coil at the right edge by varying the extraction voltage from 1 kV to 3 kV with an increase of 0.5 kV. At the extraction voltage of 1 kV to 3 kV, the total extracted beam current was obtained 33.4 A; 35.7 A; 47.8 A and 57.2 A, while the Faraday Cup measured 1.2 A; 1.5 A; 2.1 A, 2.4 A and 1.2 A.

Based on the experimental data it is known that the pulsed electron beam can be extracted. Figures 3 up to 5 show that the greater the extraction voltage will produce a large beam current. The plasma arc discharge is not entirely homogeneous, this is indicated by the value of the beam current at the extraction voltage of 1 to 3 kV beam position near the ignitor electrode is higher than the middle position.
5. Conclusion

From the measurement results obtained a current spot plasma is 11.24 A and a plasma arc is 119.65 A. At the position near the electrode ignitor a maximum extraction current is 13.1 A can be obtained with an extraction voltage of 3 kV, while at the center of the position is grid 6,7 A, so that the beam distribution obtained near the ignitor electrode is higher than in the middle position of the grid.

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