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OPTIMIZATION OF OPERATION PARAMETERS OF 80-KEV ELECTRON GUN

JEONG DONG KIM[1*], YONGDEOK LEE[1], and HEUNG SIK KANG[2]
[1]Korea Atomic Energy Research Institute
989-111, Daedeok-daero, Yuseong-gu, Daejeon, 305-353 KOREA
[2]Pohang Accelerator Laboratory
San 31, Hyoja-dong, Pohang, kyungbuk, 790-857 KOREA
[*]Corresponding author. E-mail : kjd@kaeri.re.kr

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A Slowing Down Time Spectrometer (SDTS) system is a highly efficient technique for isotopic nuclear material content analysis. SDTS technology has been used to analyze spent nuclear fuel and the pyro-processing of spent fuel. SDTS requires an external neutron source to induce the isotopic fissile fission. A high intensity neutron source is required to ensure a high for a good fissile fission. The electron linear accelerator system was selected to generate proper source neutrons efficiently.

As a first step, the electron generator of an 80-keV electron gun was manufactured. In order to produce the high beam power from electron linear accelerator, a proper beam current is required form the electron generator. In this study, the beam current was measured by evaluating the performance of the electron generator. The beam current was determined by five parameters: high voltage at the electron gun, cathode voltage, pulse width, pulse amplitude, and bias voltage at the grid. From the experimental results under optimal conditions, the high voltage was determined to be 80 kV, the pulse width was 500 ns, and the cathode voltage was from 4.2 V to 4.6 V. The beam current was measured as 1.9 A at maximum. These results satisfy the beam current required for the operation of an electron linear accelerator.

KEYWORDS : SDTS, Source Neutron, Electron Linear Accelerator, Electron Generator, Beam Current

1. INTRODUCTION

A Slowing Down Time Spectrometer (SDTS) has been developed to analyze spent nuclear fuel and a pyro-processing of spent fuel [1,2]. Spent nuclear fuel emits intense radiation, and thus direct isotope fission analysis is difficult. However, SDTS has a feature for a direct isotopic fissile analysis for spent fuel [3,4,5]. It is not influenced by the intense background radiation such as neutrons and gamma rays from spent fuel. Therefore, SDTS is the most feasible technology to analyze isotopic fissile material content directly. SDTS needs an external neutron source because it induces the isotopic fissile fission. Therefore, the neutron source must be intense and have good energy resolution in a wide energy range.

Existing neutron generators are D-T and D-D. However, the neutron source intensity of existing neutron generators is weak. They do not meet the source neutron intensity required for an SDTS system. Therefore, a compact, cost effective, and easy to maintain electron linear accelerator was considered. In case of the 30MeV electron beam incident on target, it can produce 10^{12} n/s which is sufficient for an SDTS system to induce fissile fission and overcome background radiation. Therefore, the electron linear accelerator is proper for source neutron generation. The source neutron is produced between the electron beam and a metal target by an $(e,\gamma)(\gamma,n)$ reaction in the target [6,7]. The intensity of the source neutrons generated are sufficient for the source neutron intensity required in an SDTS system. The electron linear accelerator must be considered highly efficient source neutron production and flexible size depending on the beam power.

Currently, a compact electron linear accelerator proper for an SDTS system is being developed. As a first step, an 80-keV electron gun was designed and manufactured. It consists of an anode, a cathode, and a grid. The accelerating voltage of the electron gun is adjustable up to 80kV, and the generated current is 5 A at maximum. An electron generator was then manufactured. It consists of an electron gun, a high voltage power supply, a bias power supply, a pulse generator, and a vacuum system. In order for the electron linear accelerator to have high beam power, a proper beam current is required. The beam current is determined by five parameters. Those are high voltage, cathode voltage, pulse width, pulse amplitude, and bias voltage. 0.5 A is currently considered the operation current of the electron linear accelerator. A loss of about 50% is expected while the electron beam passes through the accelerating tube. Therefore, the minimum beam current should be over 1 A at the electron generator.

In this study, a beam current of approximately 1A to 2 A was produced by the selection of appropriate operation parameters of the electron generator. Experimental results are provided to select a proper beam current when operating a linear electron accelerator.

2. SYSTEM CONFIGURATION

The electron beam from the electron gun is generated when the pulse is triggered to the gun. Fig. 1 shows the circuit diagram of the electron gun. The wall feature of the inside of the electron gun is designed such that the electron beam generated can be focused by the electric field. The thermal electrons generated on the cathode are accelerated by the potential difference between the cathode and grid. In order to prevent the emission of the electrons toward the anode, a positive voltage was applied to the grid. If the acceleration voltage is applied between the cathode and grid, electrons are accelerated to pass the grid.

Fig. 2 shows a schematic of the electron generator system. It consists of an electron gun, high voltage power supply, cathode heater power supply, high voltage deck, Isolation transformer, bias power supply, pulse generator, and vacuum system. Fig. 3 shows the overall appearance of the electron generating apparatus. The E - gun consists of an anode, a cathode, and a grid. The accelerating voltage of the electron gun is adjustable up to 80kV, and the generated current is 5 A at maximum. The high voltage power supply provides the acceleration voltage at the grid. The intensity of the electron beam is changed by the acceleration voltage which can be up to 80kV. The cathode heater power gives a device for heating the filament of the cathode. The thermal electrons generated by the heated filament. It is accelerated to the electron beam. Bias power supply is applied to the positive voltage at the gird. The feature of the gird prevent to thermal electrons emission toward the anode. The pulse generator creates a pulse with

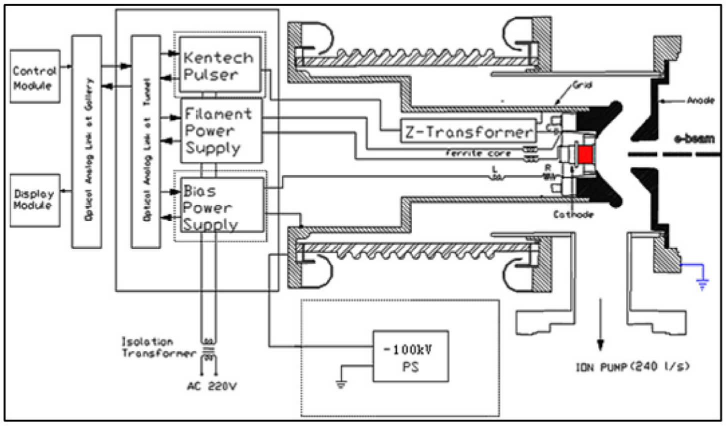

Fig. 1. Circuit Diagram of 80-keV Electron-gun

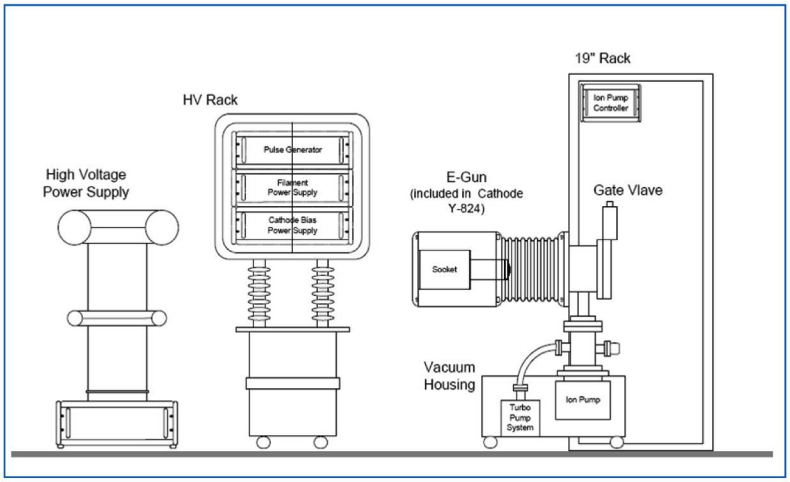

Fig. 2. Electron Generator System Schematic

a negative voltage. When a pulse is generated, the electron is accelerated. The vacuum system is composed of a vacuum chamber, ion pump, vacuum gauge, vacuum valve, and turbo pump system. The vacuum level inside the electron gun should be maintained at less than $5x10^{-9}$ Torr.

3. NEUTRON YIELDS AND BEAM CURRENT MEASUREMENT

3.1 The Number of Electrons in the Beam

Generally, the number of electrons is proportional to the beam current. Electrons flow at about 6.242E + 18 electron/c. Using the beam current, the pulse width and frequency the total number of electrons can be calculated by Eq. (1).

$$\mathrm{N}_E = \mathrm{A} \times \mathrm{F} \times \mathrm{H} \times 6.242 \times 10^{18} \tag{1}$$

Where $\mathrm{N_E}$ is the total number of electrons, A is the beam current at the electron generator, F is the pulse width and H is the frequency of the pulse generator. Considering the specification of the linear electron accelerator, the beam current is 0.6 A, the pulse width is 500 ns, and the frequency is 240 Hz. The total number of electrons is calculated by Eq. (2). As a result, the number of electrons in the beam is about 4.5e+14 electrons/s

$$0.6\mathrm{A} \times 500\mathrm{ns} \times 240\mathrm{Hz} \times 6.242\mathrm{E} + 18\ \mathrm{electrons/c} = 4.5\mathrm{e} + 14\ \mathrm{electrons} \tag{2}$$

3.2 Evaluation of the Neutron Yields

The number of neutrons generated by one electron was calculated using the Monte-Carlo method. The number of neutrons generated is about 5E-5n/cm^2 on the surface area of the target. This is the neutron flux. Multiplying the surface area of the target by the neutron flux, gives the neutron generation rate. The surface area of the target is 200 cm^2. As a result, neutrons were generated at about 1E-2n/s.

$$N_n = N_E \times 1E - 2\ \mathrm{n/s} = 4.5e + 12\ \mathrm{n/s} \tag{3}$$

Using the number of electrons in the beam and the neutron generation rate of the surface area of the target, the neutron yield is calculated by Eq. (3). It is about 4.5e+12 n/s.

3.3 Beam Current Measurement Method

The linear electron accelerator requires a beam current of at least 0.5 A. Normally, a current loss of about 50% is expected along the accelerating tube. Therefore, the minimum beam current should be over 1 A at the electron generator. Considering the beam current required for operating the electron linear accelerator, the maximum beam current was selected as 2 A. The beam current was measured using a Beam Current Monitor (BCM) and an oscilloscope. The current and pulse shape of the electron beam generated in the electron gun was observed using an oscilloscope. The real beam current was calculated with the BCM calibration data.

No	Components
1	High Voltage Supply
2	E-Gun
3	Vacuum system
4	H.V DECK
5	Isolation transformar
6	Pulse Generator
7	Bias power supply
8	Cathode power supply
9	Vacuum controler
10	Ion Purmps controler
11	High Voltage Controler

Fig. 3. Actual Appearance of the Electron Generator System

4. OPTIMIZATION OF THE BEAM PARAMETERS

4.1 Pulse Width

A relatively long pulse width was selected because more source neutrons are generated than with short pulse width. The beam current and pulse shape as a function of the pulse width were measured. In the test, the pulse width was varied from 150 ns to 700 ns. Fig. 4 shows the pulse shape as the pulse width changes. The pulse shape was well defined on a pulse width of 250 ns. In the case of the longer pulse width, the pulse shape began to deteriorate compared to that of 250 ns. This problem is related to the performance of the pulse generator. Table 1 shows the measured beam current as the pulse width increases. The bias voltage, high voltage, and pulse amplitude were maintained at the same condition. During the pulse width changed from 200 ns to 800 ns, the beam current is hardly changed because the beam current is calculated by Eq. (4).

$$\frac{V\times P\times A}{S\times P} = Beam\ current \tag{4}$$

Where V is the measured voltage by oscilloscope, P is the pulse width, A is the attenuator ratio and S is the sensitivity of the beam current monitor. The pulse width is erased in the numerator and denominator. Therefore, the beam current isn't influenced by the pulse width, as confirmed through the experiments. By considering the effective neutron generation and performance of the pulse generator, the pulse width was selected as 500 ns.

4.2 High Voltage

The accelerating voltage of the electron gun is created by the potential difference between the high voltage and ground. The beam current depends on the acceleration voltage. The high voltage was varied from 40 kV to 80 kV. Fig. 5 and 6 show the beam current and pulse shape of the electron beam as the high voltage changes. According to the cathode voltage, the degree of change in the beam current is very different. At a cathode voltage of 4.3 V, the beam current does not change by high voltage increase as shown in Fig. 5. However, in the case of the cathode voltage of 4.7 V, the beam current is increased as shown in Fig. 6, because the number of electrons generated is determined by the cathode voltage. In addition, by increasing the high voltage, the beam current is increased but the pulse shape becomes deteriorated as shown in Fig. 6. Therefore, the

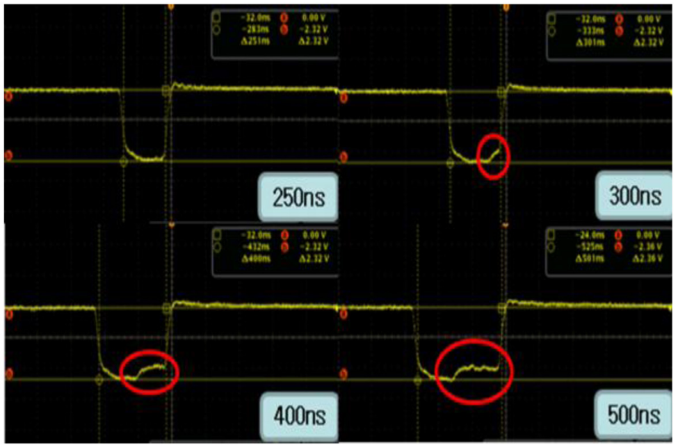

Fig. 4. Pulse Shape with the Different Pulse Widths

Table 1. Beam Current about Increasing Pulse width

Bias(V)	H.V(kV)	Pulse		Beam Current(A)
		Width(ns)	Amplitude(V)	
50	80	300	-120	1.47
50	80	400	-120	1.47
50	80	500	-120	1.47
50	80	600	-120	1.47
50	80	700	-120	1.45
50	80	800	-120	1.45

beam current increases proportionally to the high voltage. The electron beam generated from the electron generator may happen to get lost at the pre-buncher and buncher. The beam loss can be minimized at 80 kV. In addition, the beam current is at maximum at 80 kV. Therefore the optimum high voltage was selected as 80 kV.

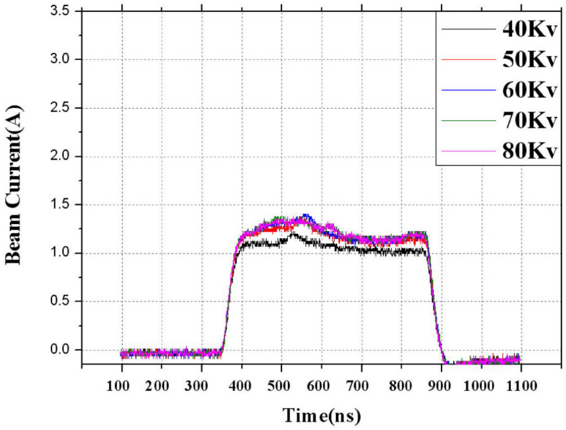

Fig. 5. Pulse Shape as the High Voltage Increases at the Cathode Voltage of 4.3 V

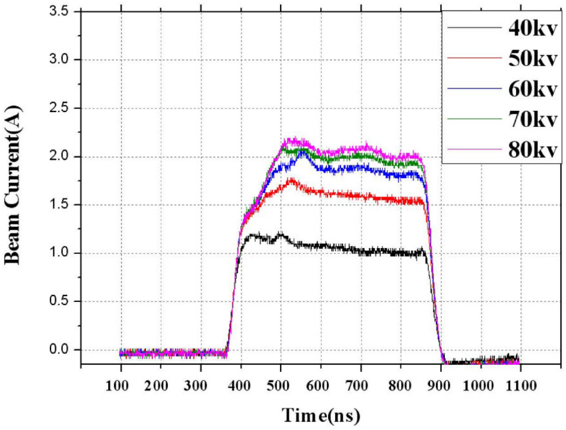

Fig. 6. Pulse Shape as the High Voltage Increases at the Cathode Voltage of 4.7 V

4.3 Cathode Voltage

The number of electrons generated is proportional to the cathode voltage. Therefore, the cathode voltage has a direct effect on the beam current. As the experimental conditions, the bias voltage was 50 V, the high voltage was 80 kV, the pulse width was 500 ns, and the pulse amplitude was -100 V. The cathode voltage range was from 4.2 V to 4.7 V. Table 2 shows the beam current as the cathode voltage increases. If the cathode voltage is raised by 0.1 V, the cathode current increases by approximately 0.6 A. The beam current was measured from 1.01 V to 1.85 V. Before, the beam current rage was determined as 1 A to 2 A. Therefore, the cathode voltage was selected as 4.2 V to 4.7 V.

4.4 DIfference Voltage between Bias and Pulse Amplitude

The beam current is proportional to the difference between the bias voltage and pulse amplitude voltage. The bias voltage was usually a positive value, and the pulse amplitude voltage was normally a negative value. If the voltage difference increased, the number of electrons passing the grid increased. As a result, the beam current also increased. In case of the higher voltage difference between bias voltage and pulse amplitude voltage, A higher beam current was measured. However, the voltage difference was limited. If the voltage difference goes over a certain level, a satellite pulse appears as shown in Fig. 7. Therefore the appropriate voltage difference is important to find. In addition, Fig. 8 shows the pulse shape as the bias voltage increases. When the bias voltage increases, the pulse shape is deteriorated. Therefore, the bias voltage was selected as 50 V in order to find the appropriate voltage difference. The pulse amplitude voltage must be over -100 V in order to generate a sufficient beam current. Therefore, the minimum voltage difference is -50 V. However, according to the cathode voltage, the maximum voltage difference between bias voltage and pulse amplitude voltage is different. Maximum voltage difference was determined through experiments in many cases. Table 3 shows the beam current

Table 2. Beam Current as a Function of Cathode Voltage

Cathode		Bias(V)	H.V(V)	Pulse		Beam Current(A)
voltage(V)	Current(A)			Width(ns)	Amplitude(V)	
4.2	4.28	50	80	500	-100	1.01
4.3	4.37	50	80	500	-100	1.08
4.4	4.43	50	80	500	-100	1.12
4.5	4.49	50	80	500	-100	1.35
4.6	4.56	50	80	500	-100	1.63
4.7	4.62	50	80	500	-100	1.85

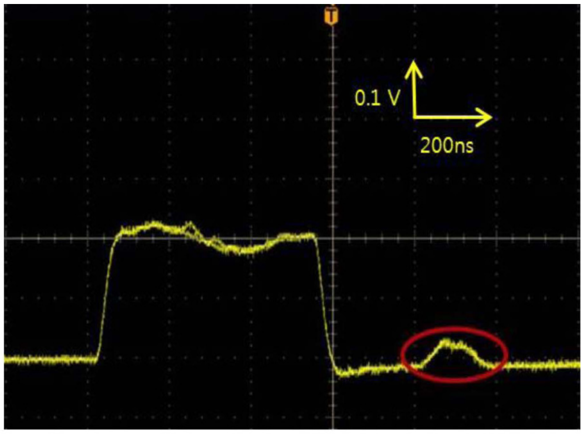

Fig. 7. A satellite Pulse

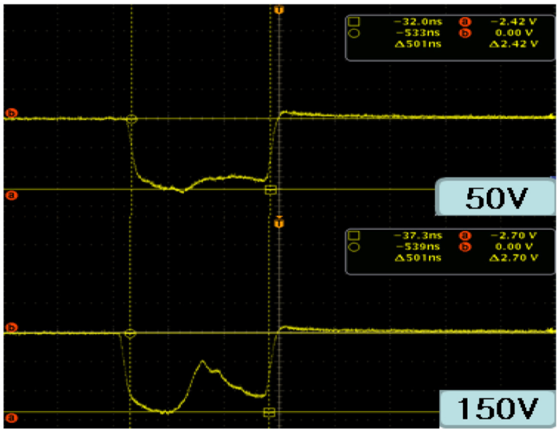

Fig. 8. Pulse Shape with Increasing Bias Voltage

Table 3. Beam Current about Bias Voltage and Pulse Amplitude Difference

Cathode(V)	Bias voltage(V)	Pulse amplitude(V)		Voltage difference(V)		BCM(A)
		Min	Max	Min	Max	
4.2	50	-100	-140	-50	-90	1.01
4.3	50	-100	-150	-50	-100	1.08 ~ 1.21
4.4	50	-100	-160	-50	-110	1.12 ~ 1.46
4.5	50	-100	-180	-50	-130	1.35 ~ 1.70
4.6	50	-100	-190	-50	-140	1.63 ~ 1.90
4.7	50r	-100	-190	-50	-140	1.85 ~ 2.20

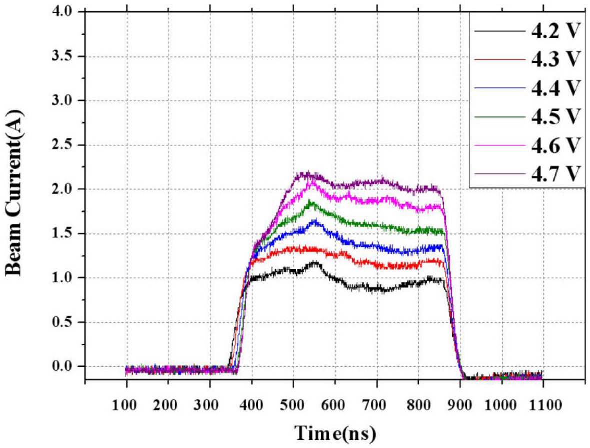

Fig. 9. Beam Current and Shape on the Minimum Voltage Difference

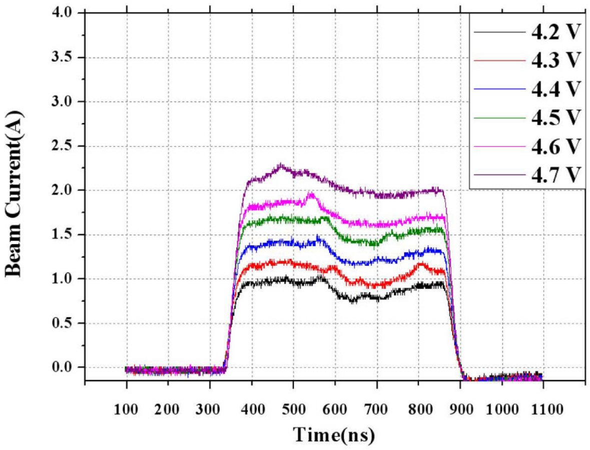

Fig. 10. Beam Current and Shape on the Maximum Voltage Difference

as a function of the difference in the cathode voltage. When operating the electron linear accelerator, the maximum beam current was selected as 2A. For the maximum voltage difference, a cathode voltage was selected between 4.2 V and 4.6 V. Fig. 9 shows the beam shape and beam current of the minimum voltage difference. Fig. 10 shows the beam shape and beam current of the maximum voltage difference. According to the increase in the cathode voltage, the beam current is increased. In case of the voltage difference was the biggest, it was confirmed that the front part

Table 4. Optimal Conditions of Beam Parameters

Cathode voltage(V)	High volte(kV)	Bias Volte(v)	Pulse		Beam Current(A)
			Width(ns)	Amplitude(v)	
4.2	80	50	500	-140	1.01
4.3	80	50	500	-150	1.21
4.4	80	50	500	-160	1.46
4.5	80	50	500	-180	1.70
4.6	80	50	500	-190	1.90

of the pulse shape was improved. Because of the number of electrons passing through the grid is maximized. As a result, the beam current is increased and the pulse shape is improved.

5. RESULTS

The optimal operation parameters were selected through an experiment on the variability of the beam current. Table 4 shows the optimal conditions of the beam current parameters. Considering efficient neutron generation and the performance of the pulse generator, the pulse width was selected as 500 ns. If the pulse width is over 250 ns, the pulse height is decreased owing to the pulse generator performance. Also, the beam current isn't influenced by the pulse width. The high voltage of 80 kV was selected to reduce the beam current loss at the buncher and pre-buncher. Also a high beam current was measured. The cathode voltage is the main parameter affecting the beam current because the electrons are generated by the cathode voltage. From the experimental results, the cathode voltage was selected from 4.2 V to 4.6 V. Finally, the voltage difference between the bias voltage and pulse amplitude was selected as max. The bias voltage was fixed at 50 V, and the pulse amplitude was changed. The voltage difference differs according to the cathode voltage. The greatest voltage difference gives a high beam current. In addition, the pulse shape is improved because the number of electrons through the grid at the maximum voltage difference is increased.

As a result, the beam current was measured as 1.0 A, 1.2 A, 1.4 A, 1.7 A, and 1.9 A. The result was satisfied the beam current required for operating the electron linear accelerator.

6. COUNCLUSIONS

A Slowing Down Time Spectrometer (SDTS) has been developed to analyze spent nuclear fuel and the pyro-processing of spent fuel. SDTS is the most feasible technology among the non-destructive techniques to analyze isotopic fissile material contents directly. SDTS requires an external neutron source. Therefore, the electron linear accelerator was selected to generate neutrons efficiently. In order for the electron linear accelerator to have a high beam power, a proper beam current is required. Currently, compact linear electronic accelerators proper for an SDTS system are being developed. An electron generator with an 80-keV electron gun was manufactured. However, about a 50% loss in current is expected while the electron beam passes through the accelerating tube. Therefore, the minimum beam current should be 1 A to 2 A to get high power neutron production. The optimal conditions of the electron generator were selected through an experiment on the variable of the beam current. The pulse width was determined as 500 ns, the high voltage was 80 kV, the cathode voltage was from 4.2 V to 4.6 V, and the voltage difference between bias voltage and pulse amplitude was the maximum level. The beam current was measured as 1.9 A at maximum.

In this study, approximately a 1 A to 2 A beam current was produced through the selection of appropriate beam parameter values in an electron generator. Experimental results are provided to select the proper beam current when operating a linear electron accelerator.

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