Development of the scanning power supply for 300 keV electron accelerator

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\textbf{Abstract.} This paper describes the development and study of the scanning power supply. This locally designed low energy electron accelerator with the former energy of 140 keV will be upgraded to 300 keV. As the setup, scanning power supply is required to excite the scanning coils and deflect the energetic electron beam across a titanium foil window in horizontal and vertical direction respectively. The excitation current of the scanning coils is determined by the energy of the electron beam and the deflected length. Therefore, the scanning power supply must be functioning automatically and continuously to ensure the uniform dose distribution and unavoidable heat issue. As the result, the scanning power supply using the combination of signal generator and power amplifier has been developed and functioning as expected.

1. Introduction

Accelerator is a promising and advanced technology with the capability to support various applications such as flue gases treatment and cable cross linking [1], medical applications such as cancer therapy and isotope production [2][3], as a collider for high energy physic experiment and study [4][5] and agriculture for mutation breeding [6]. In Nuclear Malaysia, a localized own developed accelerator technology so-called the low energy electron accelerator [7][8][9] has been upgraded from 140 keV to 300 keV as shown in Figure 1. For such improvement, other auxiliary systems must be upgraded as well such as insulating gas system [8], window cooling system [9], filament power supply [10] and scanning power supply etc. In this paper, the principle and the development of the scanning power supply will be described and discussed.
2. Parameters of the scanning power supply

Basically, an electron accelerator is a machine to accelerate the electron beam with the required energy and beam current. Whereby, the electron is produced by heating-up the filament or cathode. The heated filament will produce the electron on the surface and with a small applied electric field the electron is extracted and propagate along the accelerating tube. Finally, the energetic electron beam is scanning along the titanium foil window by two pairs of scanning coils as X-axis and Y-axis coil with optimize frequencies respectively [11]. In this low energy electron accelerator, the scanning coils are embedded at the bottom of the accelerating tube as shown in Figure 2, and the specifications of the scanning coils are shown in Table 1.

![Figure 1. Low energy electron accelerator](image1)

![Figure 2. Side view of the accelerating tube with the scanning coils embedded position.](image2)
Table 1. Specifications of the scanning coils.

| Parameters                              | Figure |
|-----------------------------------------|--------|
| Materials                               | Copper |
| Diameter                                | 3 mm   |
| Maximum excitation current              | 3 A    |
| Number of turns for X-axis coil         | 200 turns |
| Number of turns for Y-axis coil         | 200 turns |

Basically, the required scanning excitation current and frequency is determined by the energy of the electron beam and the size of the scanning window [11]. As shown in Figure 3, the window size with the length of 192.5 mm and width as 97.5 mm.

![Figure 3. Overview of the scanning horn [11].](image)

At first the desired or optimum frequency must be determined by referring to the physical geometry of the window and the electron beam diameter. According to expression as below,

\[
\eta = \frac{x}{2d} 
\]

(1)

\[
\eta = 2K 
\]

(2)

\[
K = \frac{f_{HF}}{f_{LF}} 
\]

(3)

where:

\( \eta \) is the window length coefficient,

\( K \) is the factor of high frequency and low frequency ratio,

\( x \) is the length of the scanning window,

\( d \) is the electron beam diameter,

\( f_{HF} \) is the scanning frequency of Y-axis coil and,

\( f_{LF} \) is the scanning frequency of X-axis coil.
From Figure 4, the electron beam diameter, \( d \) is measured by using a photosensitivity paper as 9 mm. Therefore, with the length as 192.5 mm and from (5), (6) \( \eta \) is 10.694, \( K \) is 5.3472.

![Figure 4](image1.png)

**Figure 4.** Electron beam size measured by photosensitivity paper.

For defined of those frequencies, the high frequency is defined as 900 Hz (< 1 kHz due to the power of the scanning power supply issue). From Equation (3), the low frequency magnitude is defined as 170 Hz.

After the frequency parameters have been identified. The second stage is to identify the required excitation current for the scanning coil. Therefore, the maximum desired magnetic field by as shown in Figure 5 must be identified, by the relationship between the magnetic field density and the required excitation current, the expression as shown in equations below [11].

![Figure 5](image2.png)

**Figure 5.** Electron beam trajectory with the interaction of magnetic field (\( h=840 \text{ mm}, x=192.5 \text{ mm} \) and \( y=97.5 \text{ mm} \)) [11]
\[ I_x = \frac{B_{\text{max},x} - 0.1476}{14.2835} \] (4)

\[ I_y = \frac{B_{\text{max},y} - 0.0399}{14.7297} \] (5)

whereby,

\[ B_{\text{max}} = \sin \varphi \left( \frac{BR}{l_{\text{eff}}} \right) \] (6)

where [11], \( l_{\text{eff},x} \) as 0.1198 m and \( l_{\text{eff},y} \) as 0.1134 m.

\[ BR = \sqrt{\frac{r^2 + 2TE}{300}} \quad [\text{MeV}] \] (7)

For the scanning pattern, the triangle waveform as shown in the Figure 6 is required [11],

\[ I_{\text{rms-half}}(x,y) = \frac{I_{\text{peak}(x,y)}}{\sqrt{3}} \] (8)

\[ I_{\text{rms}(x,y)} = 2X \left( \frac{I_{\text{peak}(x,y)}}{\sqrt{3}} \right) = \frac{I_{\text{peak-peak}(x,y)}}{\sqrt{3}} \] (9)

where:

- \( I_{\text{peak-peak}} \) = Required excitation current of scanning coil
- \( I_{\text{rms}} \) = Observed current at the current meter or digital multimeter

According to [11] and from Equation (4) to (9), the required excitation current for energy up to 300 keV is plotted as shown in Figure 7. At energy of 300 keV, the reading or observed current must be 1.60 A and 0.84 A for X-axis and Y-axis respectively.
3. Specs and configuration of the scanning power supply

Basically, the scanning power supply of the low energy electron accelerator is required to scan the electron beam along the titanium foil window horizontally and vertically. Whereby the frequencies have been identified as 170 Hz for X-axis and 900 Hz for Y-axis. By the simple configuration of the scanning power supply, the signal generator with triangle waveform is required and this small magnitude input must be amplified through an amplifier to supplying the desired excitation current to the scanning coils respectively as shown in Figure 8.
The specification of the signal generator FY6800 and power amplifier of AE 8101 as shown in Table 2 and Table 3.

**Figure 8.** Configuration of the scanning power supply.

**Table 2.** Specification of the signal generator FY6800 [12].

| Parameters          | Figure |
|---------------------|--------|
| Waveforms           | Sine, Square (Duty Cycle adjustable), Pulse (Pulse width and cycle time can be set accurately), Triangle/Ramp, Sawtooth Wave, CMOS, Four channels TTL, DC, Half wave, Full wave, Positive Step, Inverse Step, Positive Exponent, Inverse Exponent, Lorenz Pulse, Multitone, Noise, ECG, Trapezoidal Pulse, Sinc Pulse, Narrow Pulse, Gauss White Noise, AM, FM, and other 64 sets customer-defined waveform |
| Waveform Length     | 8192 points * 14bits |
| Sampling Rate       | 250MSa/s |
| Vertical Resolution | 14 bits |
| Amplitude (VPP)     | Frequency ≤ 10MHz; 1mVpp~20Vpp; 10MHz20MHz: 1mVpp~5Vpp; 50Ω±10% (Typical) |

**Table 3.** Specs of the power amplifier AE 8101 [13].

| Parameters                  | Figure |
|-----------------------------|--------|
| Frequency Response          | ± 0.25 dB from 10 Hz to 20 kHz at 1 watt |
| Input Impedance (nominally balanced, nominally 10 k ohms, 5 k ohms. unbalanced) | |
| Maximum Input Voltage       | ± 10 V balanced or unbalanced |
| Load Impedance              | Dual: 2, 4, 8, 16 Ohm |
|                            | Bridge Mono: 4, 8, 16 Ohm |
For this configuration, the input signal is controllable and the gain controller of the power amplifier is fixed. Whereby the excitation current is adjusted by controlling the input signal (manually) of the signal generator. The expected results have been obtained as discussed in next section.

4. Result and discussion
For the configuration as shown in Fig. 8, the results have been recorded by an oscilloscope as shown in Figure 9 and Figure 10. Whereby the parameter for Y-axis is 900 Hz and X-axis 170 Hz, input signal as 12 V and the gain factor is fixed as 10 dB.

![Figure 9. Voltage supplying to the Y-axis coil with triangle waveform of 900 Hz (Probe ratio is 10:1).](image1)

![Figure 10. Voltage supplying to the X-axis coil with triangle waveform of 170 Hz (Probe ratio is 10:1).](image2)

As the result, the Y-axis coils with the frequency of 900 Hz is capable of supplying 0.23 A (rms value). Meanwhile the X-axis with 170 Hz is capable of supplying 1.02 A (rms value). Both condition with the gain of 10 dB (maximum capability of power amplifier 20 dB), but the excitation current is different and this discrepancy is caused by the impedance of the coil that is directly dependent on the input signal frequency. Therefore, we could estimate the higher power is required with higher frequency. But in the physical geometry of the window, the width of the window is much shorter than the length as shown in Figure 3 Therefore, the desired scanning path along the Y-axis is much shorter than the X-axis. It means the excitation current of the Y-axis is smaller than the X-axis as well. Although, the scanning power supply is compatible with our needs but the specification of the power amplifier should be improved to scan the electron beam along the full size of the window. Although the expected current
is still a bit lower as required for 300 keV electron beam, but at the current situation this accelerator is operated at 200 keV, therefore the current specs of the scanning power supply could satisfy our need.

5. Conclusion
In this paper, parameter of the scanning power supply has been identified and developed. Furthermore, the performance of the scanning power supply has been tested and expected excitation current is observed. In near future, the scanning power supply controlled by an automated PC-based centralize control system will be studied and developed as well.

6. References
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