Study on the window cooling system of 300 keV Electron Accelerator

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Abstract. This paper describes the method used to identify the parameters required for the window cooling system. This locally designed low energy electron accelerator with the present energy of 140 keV will be upgraded to 300 keV. The heat will be increased due to the increment of the beam energy; therefore an appropriate cooling system is required to prevent the breaking of the few µm titanium window. The broken window will disrupt the beam transportation inside the vacuum environment of the accelerating tube and also the high voltage will be breakdown if the vacuum environment couldn’t be sustained. Therefore, a desired air cooling system to cool down the 9 kwatt (30 mA, 300 keV) beam power has been designed. As the result, the window cooling system with the required pressure based on the beam powers have been calculated and identified.

1. Introduction
Accelerator is a promising technology widely used in 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 [7] has been started with the initial energy of 140 keV as shown in figure 1, the so-called the low energy electron accelerator. In the present status, this accelerator is under-going upgrade works from the energy 140 keV to 300 keV with the replacement of the high voltage power supply, including the development or modification of the individual supporting systems such as scanning system, gas insulating system, window cooling system and etc. In this paper, the principle of the window cooling system will be described and discussed.
2. **Principle of Electron Accelerator**

Basically, an electron accelerator is a tool to accelerate the electron beam with the required energy and beam current which are mainly determined by the applications. The industrial electrostatic electron accelerator (ELV-4) [8] comprises of a source (cathode) to produce an electron beam by filament heating system, an accelerating element to accelerate the electron beam by the accelerating tube supplying with the high voltage supply and shielded by the insulation gas system, guiding element to guide an electron beam (beam scanning) and auxiliary systems such as vacuum system to provide a vacuum environment, a window cooling system (air cooling) to avoid the breakdown of the window due to the beam heating and several power supplies to heat up the filament and scan the beam horizontally and vertically. The combination of all the individual system is required to deliver the energetic electron beam to the user. In this paper, we're focused on the window cooling system and the detail will be discussed in the next section.

3. **Design and requirement of the window cooling system**

Basically, the window cooling system of the low energy electron accelerator consists of the air blower and coupling with the air ducting as shown in figure 2. It is required to cool down the titanium window with the thickness of 25 µm. The titanium window must be cooled down below the titanium foil breaking point temperature of 400 °C [8], it is essential to avoid the vacuum breakdown which could disturb the electron beam transportation and moreover the breakdown of the vacuum environment will cause the corona discharge inside the accelerating tube [8]. Therefore, the design of the window cooling system must be considered those parameters such as thickness of the titanium window, heating
temperature is depending on the beam energy and beam power; the required air velocity for window cooling must be identified according to those parameters.

**Figure 2. Window Cooling System with air ducting of ELV-4**

Basically, the required air velocity of the window cooling depends on the heat loss at the titanium window. The increment of the titanium foil thickness will increase the energy loss which will be transferred to the heat energy. Subsequently, it will increase the temperature of the titanium window. The details expression and calculation are given as below:

Energy loss $E_{Ti}$ in Titanium foil of 50 μm thickness ($d_{Ti}$) is [8]:

\[ dE_{Ti,50} = 31 \text{ keV} \]  

If $dE/d(d_{Ti})$ ≈ constant and, with the thickness of titanium foil ~25 μm, then:

\[ dE_{Ti,25} = E_f = 15.5 \text{ keV} \]  

Therefore, power loss $P_{Ti}$ (watt) into the titanium foil can be estimated as:

\[ P_{Ti} = \frac{E_f I_B}{e} \]  

(3)
Moreover, maximum temperature of the titanium foil can be determined as:

\[ T_{Ti} = \frac{P_{Ti}}{\alpha A} \]  

and therefore,

\[ \alpha = \frac{P_{Ti}}{T_{Ti} A} \]  

where,

- \( E \) = Electron beam energy (MeV)
- \( d_{Ti} \) = Titanium foil thickness (cm)
- \( \rho_{Ti} \) = Titanium foil density, 4.4 (g/cm\(^3\))
- \( \alpha \) = Heat transmission coefficient (W/m\(^2\)°C\(^{-1}\))
- \( A \) = Area of scanning surface (In our system, \( A = 9.7 \text{ cm} \times 19.25 \text{ cm} \))

From equation (1) to (5), the heat transmission coefficient can be estimated. The heat transmission coefficient dependence on the cooling air velocity is shown in table 1.

| V [ms\(^{-1}\)] | 0   | 10  | 30  | 100 |
|------------------|-----|-----|-----|-----|
| \( \alpha \) [W/m\(^2\)°C\(^{-1}\)] | 0   | 40  | 110 | 250 |

From the table 1, a polynomial fitting can be applied to express the relationship velocity as, cooling air velocity, \( v \):

\[ v = 0.0007\alpha^2 + 0.2327\alpha - 0.1283 \]  

and, relative pressure, \( P \) [Pa] can be determined as:

\[ P = \frac{1}{2} \rho v^2 \]  

To sustain the titanium foil without being broken, a temperature must be maintained below 400°C [8]. Using equation (1) to (6), the required cooling air velocity and pressure are estimated with three beam currents (10 mA, 20 mA and 30 mA) and with titanium window temperature below than 400°C as shown in figure 3.

From results as shown in Figure 3, the required \( v_{min} \) for foil temperature < 300°C and 10 mA beam current is \( \sim 7.1 \text{ ms}^{-1} \); \( v_{min} \) for foil temperature < 300 °C and 20 mA beam current is \( \sim 15.4 \text{ ms}^{-1} \). \( v_{min} \) for foil temperature < 300 °C and 30 mA beam current is \( \sim 25.0 \text{ ms}^{-1} \). An air blower coupling with the inappropriate air ducting and air nozzle has been fabricated. In next section, the capability of the existing window cooling system will be discussed with the experimental setup and result.
Figure 3. Required cooling air velocity and pressure of 10 mA, 20 mA and 30 mA beam current.

By taking into account the breaking point of titanium foil at 400 °C and the maximum beam parameter of the system with 30 mA, the required air velocity in our system has been set at the reference point of 300 °C as indicated by the vertical red broken line. Therefore, we must ensure that the window cooling system must be able to provide the air velocity of 25 ms\(^{-1}\) at the maximum beam current of 30 mA.

4. Experimental results of the window cooling system

The requirement of air velocity for the window cooling has been identified as shown in figure 3. Therefore, we must ensure that the present system must be fulfilled the identified magnitude. For this purpose, two experiments have been carried out as i) air velocity measurement with the different position of air ducting, ii) air velocity measurement within the window surface. The experimental setups are shown in figure 4 and figure 6. Meanwhile the experimental results are shown in the figure 5 and figure 7.
**Figure 4.** Experimental setup air velocity measurement with the different position of air ducting.

**Figure 5.** Experimental result air velocity measurement with the different position of air ducting.

Minimum required air blower velocity, ~25 ms\(^{-1}\) (30 mA beam current at 300 °C)
Figure 6. Experimental setup air velocity measurement within the window surface.

Figure 7. Experimental result air velocity measurement within the window surface.
From the experimental result, with the different length of air ducting, it is clearly shown that the position of the ducting is one of the essential parameter to increase the air velocity within the titanium window.

From the experimental result, within the window surface, we could state that the maximum air velocity is 33 ms\(^{-1}\) and minimum air velocity is 2.56 ms\(^{-1}\) respectively. Therefore, we could know clearly that the magnitude differ is caused by the inappropriate air nozzle without the uneven and unfixed dimension of the air nozzle. In addition, the air reluctant could be reduced with the modification of the air ducting.

5. Conclusions

In this paper, parameters of the heat generated by the beam current of 10 mA, 20 mA and 30 mA of the electron beam accelerator have been identified. Furthermore the air velocity generated by the existing window cooling system has been measured and identified experimentally. In conclusion, the existing window cooling system must be improved and modified with the additional air nozzle to provide the required air velocity equally within the titanium window.

6. References

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