Study on the filament power supply of the 300 keV electron accelerator

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Abstract. This paper describes the study and development of the filament power supply. This locally designed low energy electron accelerator with the present energy of 140 keV will be upgraded to 300 keV. The filaments are used to heating-up and produce the electron. The produced electron will be accelerated through a potential different by a DC High Voltage Power Supply (DCHVPS). Whereby this filament power supply is connected with the DCHVPS, therefore the isolation of high voltage is required. For such purpose, the specifications and the isolation mechanisms of the filament power supply have been identified. As the result, the filament power supply by using an air core transformer has been selected and developed with the required heating power.

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, the 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 been upgraded as well such as insulating gas system [8], scanning power supply [9], window cooling system [10], filament power supply and etc. In this paper, the principle and the development of the filament power supply will be described and discussed.

2. Specifications of filament
Basically, an electron accelerator is a machine used to accelerate the electron beam with the required energy and beam current which are mainly determined by the applications. 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 propagated to the accelerating tube for further acceleration. In this low energy electron accelerator, the filament is embedded at the top of the accelerating tube as shown in figure 2, and the specifications of the filament is shown in table 1.
Figure 1. Low energy electron accelerator.

Figure 2. Top and inner view of the accelerating tube with the filament embedded position.
### Table 1. Specs of the filament

| Parameters          | Figure |
|---------------------|--------|
| Life time           | 5000 hours |
| Material            | Lanthanum Hexa boride, LaB$_6$ |
| Diameter            | 10 mm  |

Basically, the required heating power is determined by the material of the filament. By referring to figure 3, the filament characteristics dependent to the heating power and temperature are well-defined. Therefore, we could identify the optimized heating power, which is ~ 50 watt. With this characteristic, the developed filament power supply must be able to supply 50 watt or higher heated power for electron beam production.

![Figure 3. Characteristics of the LaB$_6$ Filament.](image)

### 3. Design and requirement of the filament heating system

Basically, the filament heating power supply of the low energy electron accelerator is required to heat-up the filament for electron production. The filament power supply must be isolated from the high voltage source as shown in figure 1. For the high voltage isolation, several techniques are available, such as i) dynamo techniques to convert the mechanical energy to electrical energy for filament heating, ii) by using a high voltage isolation transformer for 300 kV isolation, iii) by using an air core transformer mechanism to transfer the power source indirectly to heat-up the filament. In addition, the design of the filament heating system must consider the physical geometry factor as the dimensions between the accelerating tube and pressure vessel as described in Ref. [8].
Table 2. Comparison of the three filament heating methods

|                  | Dynamo technique | Isolation transformer | Air core transformer |
|------------------|------------------|-----------------------|----------------------|
| Cost             | Θ                | ▲                      | ▲                    |
| Required space inside the pressure vessel | ▲                | ▲                      | Θ                    |
| Required space outside the pressure vessel | Θ                | ▲                      | Θ                    |
| Flexibility      | Θ                | ▲                      | ▲                    |

(▲ Easy/Low, Θ-Medium, ▲ Difficult/High)

According to table 2, the major factors are the space inside the pressure vessel and cost of the system. Therefore, we have selected the air core transformer mechanism as the filament heating system. For the design of the air core transformer mechanism, the concept is rarely simple. The concept is the same as the iron core transformer but instead of iron core, the air core will be applied as a medium to transfer the power from the primary winding to the secondary winding and connected to a matching transformer that connected to the filament. Whereby the filament heating system is located inside the pressure vessel [8], as surrounding by the nitrogen gas as a high voltage insulation medium. For detail parameters optimization, few experiments have been performed as described in next section.

4. Experimental

For the air core transformer mechanism, the parameters such as diameter, number of turns of primary and secondary windings and the power transfer efficiency by a matching transformer must been identified, therefore 3 experiments have been carried out as:

i) To define the physical diameter of primary and secondary windings

For this experimental, the physical diameter optimization for the secondary winding is referred to the magnetic flux density, B induced from the primary winding. Whereby the diameter of the primary winding geometry is fixed as 645 mm and 216 turns, which is determined by the diameter of the pressure vessel. As the result as shown in figure 4, the induced B losses ~30% at 270 mm distance from the center as indicated with the red line. Moreover the distance between secondary winding and primary winding is crucial to avoid the high voltage discharge because the secondary winding is contacted with the high voltage source. From ref. 8, with respect to the distance of both windings of 5 cm is compatible with the specification of the gas pressure system, therefore the optimized diameter of secondary winding has been fixed as 545 mm as shown in figure 5.

ii) To define the number of turns of primary and secondary windings

With the optimization of each winding’s diameters, the number of turns is fixed with 147 turns for primary winding. Whereby this number of turns is based on the winding quantity stored at the laboratory. By considering the voltage increment of ~3 times, the number of turns for secondary winding is selected as ~416 turns, which is taking account with the available stock in the laboratory as well. As shown in figure 6: the main power source of variable transformer is set as the primary winding input, the secondary winding is connected with a matching transformer, whereby the matching transformer (60-0-60) is connected filament, LaB₆. As shown in figure 7, the achievable power output power is ~24 watt at 150 Vac input and the required heating power is unexpected with this setup even with 240 Vac. Therefore, the specs of the matching transformer must be optimized as described below.
**Figure 4.** Magnetic flux density induced by the primary winding with the reference position from the center of the diameter as “0”

**Figure 5.** Overview of the Air Core Transformer Power Supply
iii) To optimize the power transfer for filament heating by using a matching transformer

According to figure 7, the output voltage is too low, which is incompatible with the output current. Therefore, the matching transformer is required to be changed by the spec of 60-0-60 to 30-0-30. Whereby the setup of the experiment is same as shown in figure 6, only
the matching transformer is changed. The result has been improved tremendously by two
times as shown in figure 8.

![Graph showing Vp Vs I & P](image)

**Figure 8.** Performance Heating Power with Two Matching Transformer as 60-0-60 and 30-0-30

As the result, the filament power supply with the capability of heating up the filament for 50 watt or higher has been designed and developed. Although, the specs is compatible with our needs but the temperature arise issue during the long time heating must been considered in near future

5. Conclusion
In this paper, parameters of the filament power supply has been identified and developed. Furthermore, the performance of the filament power supply has been tested and the required heating power of 50 watt is achieved. In near future, the filament power supply by using the air core mechanism will be tested using the nitrogen gas inside the pressure vessel and, a motorized control manner will be implemented as well.

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