DEVELOPMENT OF PORTABLE DC ELECTRON ACCELERATOR WITH AIR-CORE TRANSFORMER

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Abstract

A light and portable DC-electron accelerator with the cascade silicone-molded transformer is designed and fabricated for material processing. The potential and the current of the electron beam are 400 kV and 40 mA, respectively. This accelerator system is composed of inverter of 2kHz frequency, high voltage generating components, electron gun and spraying components. This system is feed-back controlled depending on moving speed as a portable type. To reduce the size and weight of the device, this accelerator adopted silicone-molded transformer instead of conventional one pressurized SF_6 gas in the steel vessel for high voltage insulation. Design and fabrication details are presented.

1 INTRODUCTION

In designing the accelerator of 400kV and 40mA, the computer codes of POISSON, ETP and PSPICE were used for calculations. Newly developed accelerator in comparison with ELV of Russia is characterized in table 1.

2 DESIGN AND FABRICATION

The high voltage generator in this work consists of primary winding, sectionalized secondary windings and voltage doubling circuits(diodes, capacitor block and discharging resistors).
Primary winding is fabricated with 1mm thick copper pipe of rectangular cross-section , which provides electric power and serves as a cooling channel. Skin depth of copper at 2kHz is 1.48mm and thickness of primary and secondary coil must be below this value.
The primary coil is closely wound to enhance the coupling between primary and secondary coils and to increase inductance of primary coil and therefore to reduce primary current.
For the purpose of realizing more uniform coupling coefficient distribution between primary and secondary windings POISSON code was used.
The survey result of coupling coefficient distribution is shown in figure 1. Equalization of secondary voltage is obtained by different windings in each stage.

	ELV(Russia)	This system
Feature	***Fixed***	***Movable (Portable type)***
Insulation type	• Gas (SF_6) • Pressure vessel • Dismantlement -difficult	• Solid (Silicone, Epoxy) • Vacuum molding • Dismantlement -easy
Input frequency	• 400Hz – need large capacitance	2000Hz - need small capacitance
Frequency converter	• Motor-generator driven • Heavy and large • Very noisy	• IGBT inverter (PWM) • Small and light • A little noisy
Equalization of secondary voltage	• Different pitch of primary coil	• Closely-wound and same pitch of primary coil • Different windings of secondary coil of each stage
Coupling coefficient	0.6 ~ 0.8	0.7 ~ 0.9
Capacitor block	Horizontally mounted	Vertically mounted to reduce eddy current loss of capacitor electrode
E-gun & accelerating tube	Built-in	Isolation

Table 1: Characteristics of this accelerator in comparison to ELV

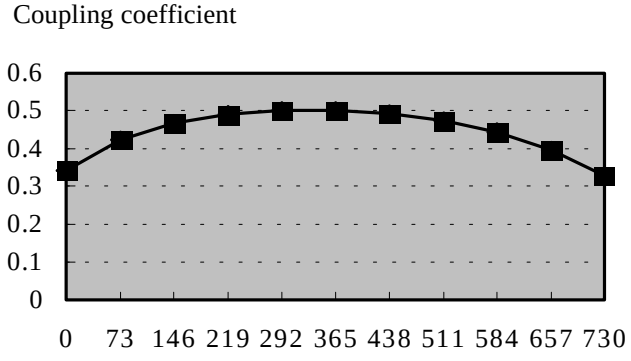

Figure 1 : The distribution of coupling coefficient

Secondary winding sections are insulated between layers and turns, which determine the dielectric strength of the transformer. Void in dielectric material strengthens electric field. So secondary coil is molded with epoxy resin in vacuum to avoid this effect. Molding with epoxy resin also supports secondary coil mechanically.

Voltage doubling circuit comprises rectifiers and capacitors whose performance is the most important barometer to the number of stages in the high voltage generator. Total stage of secondary section is 11 and the voltage of one stage is 36.3kV. The capacitance of filter capacitor block is 21nF when voltage ripple factor is 2.6%. 2kHz input frequency reduces capacitance to one fifth compared to 400Hz input frequency which is used generally.

Secondary coil and rectifying unit is molded with silicone rubber to be exchanged when rectifying components are in failure.

Injection unit of electron gun is composed of LaB_6 cathode, heater of spiral tungsten filament, heat shield made of tantalum foils and focusing electrode. Distance and voltage between cathode and anode are 45.8mm and 16kV. Figure 2 shows electron beam trajectory by ETP code simulation. The result shows that space charge limited current is 124mA .

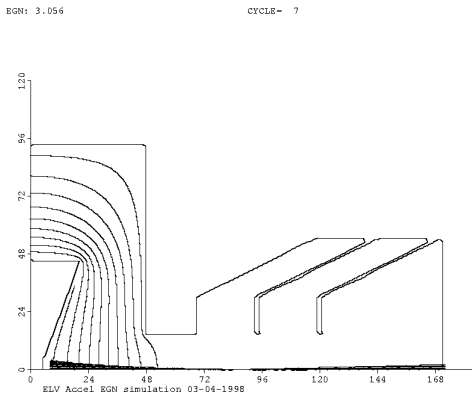

Figure 2 : Electron beam trajectory

Extracted electron beam current is controlled by the temperature of cathode, obeying Richardson-Dushman equation. In general LaB_6 which has relatively low work function 2.66eV is used for the cathode material, whose emission current density is 0.5mA/mm^2 at operating temperature 1600K. Saturable reactor is used in cathode heating power supply to obtain the required temperature of the cathode.

Accelerating tube consists of ceramic insulating ring and dish-type electrodes and voltage dividing resistors. Equipotential contours inside and outside the accelerating tube are shown in Figure 3. There was found the maximum electric field strength 27kV/mm at the corner of electrode. The total number of electrodes is 25 and the accelerating voltage between electrodes is 16kV. Accelerating tube is also molded with silicone in vacuum to avoid electrical breakdown outside it.

After the electron beam is extracted from the electron gun, it should be accelerated and transported to extraction window with minimum beam loss. The purpose of the magnetic lens is to prevent the beam from striking the bellmouth walls, prior to the beam extraction through the window foil.

There are two deflecting magnets, one of which is for high frequency and the other for low frequency. The

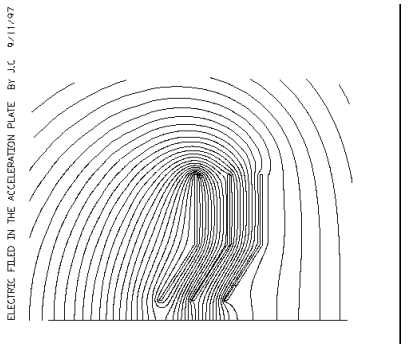

Figure 3 : Electric field in accelerating tube

high frequency deflecting magnet makes the beam scan the extraction window fast so the beam raster cannot perforate the foil due to overheating or melting. The deflection angle of the electron beam is 2°30′ horizontally and 30° vertically. And scanning frequency of the horizontal and the vertical deflection coil is 15.75kHz and 60Hz .

The extraction window is made of 30μm Ti foil, whose mechanical and thermal properties are better than those of other foils, although its beam loss is not the smallest. The sag of the foil is below the half of the foil width to avoid absorption losses in the marginal zones of the windows.

3. CONCLUSION AND FUTURE WORK

An accelerator of 400kV and 40mA with air-core transformer was designed and developed. Each component of the accelerator was fabricated. The experiment of molded high voltage generator was performed and the groundwork for development of the same type accelerator was established. All the specifications of the newly developed accelerator were determined to satisfy the dielectric strength criteria. Further works and improvements are needed to establish the stable and compact accelerator.

4. REFERENCES

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