CALCULATION AND DESIGN OF A HIGH VOLTAGE ELECTRON ACCELERATOR

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Abstract

High voltage electron accelerators are currently utilized in various industrial applications for Crosslinking Compounds, Sterilization, Polymerization, and Vulcanization, etc. The conceptual design of a high voltage electron accelerator for radiation technologies is considered in the paper. The key components of the electron accelerator are introduced and analyzed. Relevant physical parameters of the accelerator are then obtained. In order to verify the rationality of the design, beam optical paths are calculated by TRANSPORT program. The beam envelopes show that the physical design of this system can meet the requirement of engineering.

INTRODUCTION

The high voltage electron accelerator is multi-disciplinary integrated industrial equipment involving high voltage, high vacuum, electronic engineering, automatic control technology, mechanical design, beam measurement, radiation protection and so on. Any problem would affect the working of the electron accelerator as well as production, so the accelerator must be designed reliably. A 350keV electron accelerator is mainly used for film irradiation, solidification coatings, vulcanization of rubber, etc. To facilitate maintenance, an open structure of the accelerator is applied and some components like the accelerating tube are exposed to air.

A similar design scheme, which gives us a lot of help, has been developed in China Institute of Atomic Energy (CIAE) [1].

SYSTEM STRUCTURE

The accelerator mainly consists of an electron gun, an accelerating tube, a DC high voltage power supply, control system, vacuum system, scanning system, shielding system, security system, and under beam system, etc.

The electron gun and accelerating tube is the heart of the electron accelerator, and all other assemblies support it. The DC power supply creates high voltage required by the accelerator. The control system maintains the desired beam while also monitoring all aspects of the system to insure safe and reliable operation. The vacuum system maintains the required high vacuum to allow the free movement of electron. The scanning system spreads out the electron beam making it useful as a processing tool. Shielding safely stops all unused electrons and x-rays from escaping the processing chamber. The security

system insures the accelerator runs safely. Under beam system moves the product to be processed in the electron beam. Figure 1 shows the system structure.
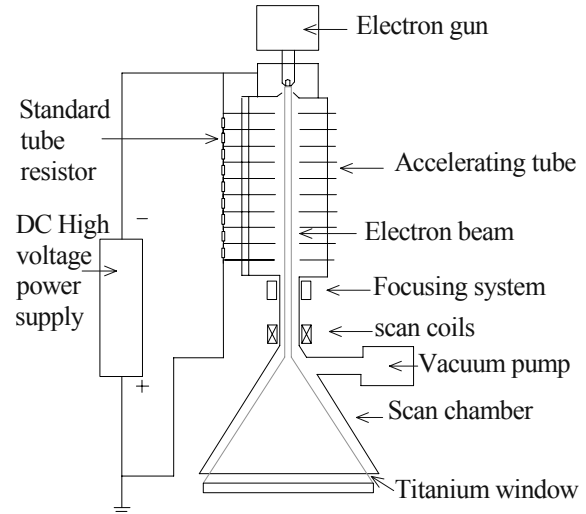

Figure1: Structure of the electron irradiation accelerator.

SUBSYSTEM

A brief introduction of some important subsystems of the high voltage electron accelerator is as follows.

Electron gun

The Electron gun is one of the core components of the accelerator aiming at producing good focusing electronic flow in a simple and reliable structure. Besides, it should have low power consumption and long service life.

The dipolar electron gun is adopted not only for its simple structure with fewer parameters to control and adjust, but also for high intensity electron beams produced and low cost.

When the electron beam intensity of the electron gun is 80 ~ 100mA and the life expectancy of the filament is longer than 10000 hours.

The electron gun consists of a hot cathode, a grid plate, a gun, and an extraction electrode. Figure 2 shows the structure.

The cathode made of wound tungsten rhenium wire has good properties and stable performance at a high temperature. A plate electrode with a hole in the centre is placed below the filament, of which the emission surface squarely faces the center of the electrode hole. The plate electrode modulates the intensity of electron flow as a grid and also help focus. The structure of the lead-out area has a direct impact on electron beam intensity from the

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electron gun and beam optical quality. Flat straight lead-out structure is adopted since the electron beam divergence angle and the beam diameter are both small. [2]
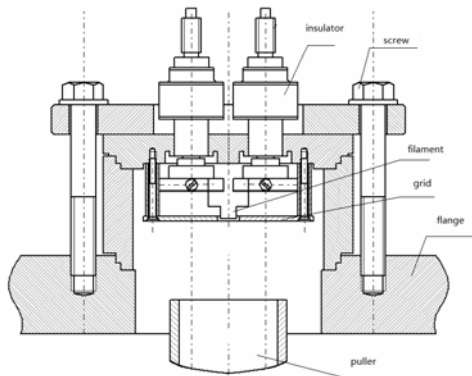

Figure 2: Structure of the electron gun.

Accelerating tube

The accelerating tube is a connection of five standard accelerating tubes, each of which is welded by 12 electrodes and 11 ceramic rings, as shown in Figure 3.

The sub-pressure resistance wraps the outside of the accelerating tube. The metal electrodes arranged evenly in the accelerating tube are also called grading ring which make electric potential to decrease evenly from top to bottom along the accelerating tube to avoid local electric breakdown, which would cause the damage to the accelerator. While the accelerating tube is working, the vacuum degree in the tube should be less than 1×10^{-4} Pa to reduce the collision probability of electrons and gas molecules and increase the efficiency of electron extraction.

Figure3 Structure of the accelerating tube

DC high power supply

High voltage power supply consists of an isolation transformer, an AC-DC-AC inverter, a step-up transformer and a high voltage multiplier. The block diagram is shown in Figure 4.

Isolation transformer is used to isolate interference from the grid to the intermediate frequency power supply and vice versa. The step-up transformer and the high voltage multiplier are placed in a steel cylinder filled with SF_6 to improve the insulation level. That requires the sizes of step-up transformer and high voltage multiplier shall be as smaller as possible. Thus the inverter of 12~ 20 kHz are applied to ensure a small enough size of the high

voltage power supply. The step-up transformer is a square wave excited transformer that meets the requirements of high conversion efficiency, good insulation and low leakage inductance and distributed capacitance. The high voltage multiplier adopts 12 levels symmetrical double voltage circuit and the output is 400kV/40mA.

The output voltage stability of the high voltage power supply: <2%, output voltage ripple: <1%.
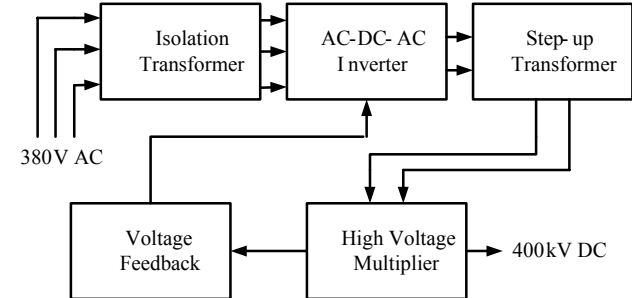

Figure 4: Structure diagram of the high voltage power supply

Control system

Control and safety interlock system is also essential for the entire radiation device. The logic control of the accelerator is achieved by PLC and working parameters are visually displayed on the computer screen. Only successful operation of each subsystem can ensure the whole system to run properly. So if there is any problem in the subsystem, the accelerator must be interlocked and apply security protection.

Signals that need to be interlocked are: vacuum, over-voltage of high voltage, over-current, doors, keys, water-cooled flow and temperature, oil flow and oil temperature, valves and scanning undercurrent flow, air-cooled flow, etc.

A distributed control system (DCS) is adopted in the accelerator which is divided into a number of relatively independent subsystems and each of them can share the control function more equally to achieve global management of the system based on communication coordination. In addition, the control system has the capability of remote access to realize remote monitoring and maintenance, so wide area network (WLAN) or local area network (LAN) is available connection mode, with TCP/IP protocol and client/server (C/S) access mode. [3]

The control system composed of a computer as master control unit, and 4 PLCs as local control unit, is in charge of the control of field devices. Figure 5 shows the system distribution diagram.

SIMENS S7-300 Series PLC will be used. The CPU module of PLC is connected by MPI bus; PLC and distributed I/O is connected by PROFIBUS; PLC and terminals, such as inverters, are linked by RS485 / 232 bus; the main PLC and the monitor computer is connected by Ethernet with TCP/IP protocol, that can realize remote monitoring and maintenance on Internet.

The software is programmed by STEP 7 and C language. Some hardware functions are implemented by

software, making the whole system easier to test, manufacture, maintain and upgrade.

When the accelerator is running, especially in the beam state, some components of the control system are in a radioactive environment of high voltage and strong electromagnetic field, which affects the long-term operation of the accelerator. So, its anti-interference capability and fault tolerance are strengthened in the design period and redundancy is left in all kinds of monitoring signals to enhance system security and stability.
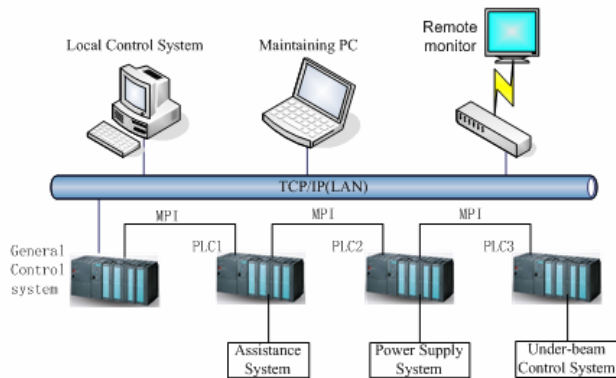

Figure 5 Distribution diagram of control system

BEAM OPTICS CALCULATION

TRANSPORT is used to calculate beam optic of the accelerator. The version of Graphic Transport is 2.57b, which is a first-，second-，and third-order matrix multiplication computer program. [4]

Extraction voltage of the electron gun is obtained from the accelerating voltage by the sub-pressure resistance, so it is easy to adjust. Solenoid is chosen as the focusing element of the accelerator. Given conditions are:

- Total accelerating voltage is 350kV.
- Total length of the accelerating tube is 1.55m.
- The vertical distance between the bottom of the accelerating tube and the center of the scanning magnet is 0.5m.
- The vertical distance between the center of the scanning magnet and the irradiated material is 0.8m.

Parameters of the electron gun are:

- Extraction voltage is 15 ~25kV.
- Extraction current is 40mA.
- Emittance is 10 mm mrad.

Constraint condition is that scanning width remains 0.9m while the vertical size of the beam spot irradiated on the titanium window cannot exceed 6cm. Due to the strong effects of space charge at low energy, we must pay more attention to it in the program. A type 22.0 card incorporates the linear part of the space-charge force into the transport line by a series of thin lenses at same intervals.
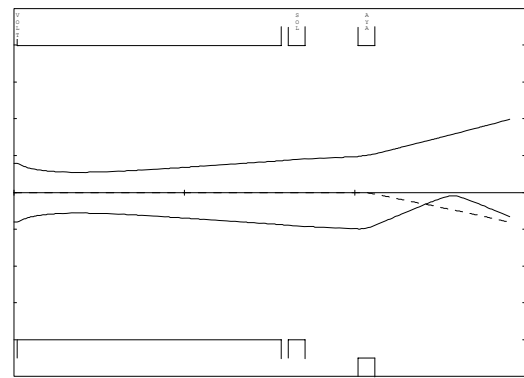
(a)
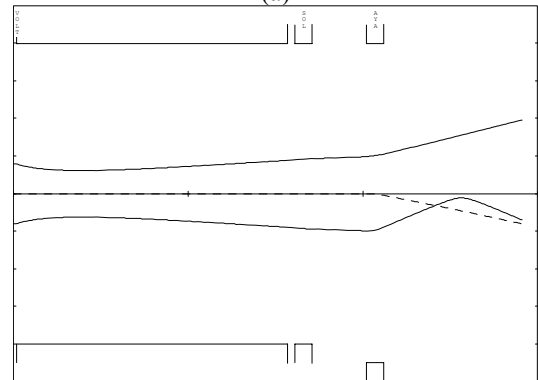
(b)

Figure6: Beam envelopes at the extraction voltage of 15kV (a) and 25kV (b). The scale of horizontal axis (Z axis) is meter, and the scale of the vertical axis is 0.5 centimetre. The upper curve represent the beam envelope in X axis, and the under is the envelope in Y axis.

Seen from the above figure, changes in the extraction voltage from 15kV to 25kV have little effect on beam envelopes of the accelerator, and the spot size maintains within the required range.

CONCLUSION

In this paper, the conceptual design of a high voltage electron accelerator has been suggested. TRANSPORT program is used to verify the rationality of the design. The results of the calculation show that the physical design of this system can meet the requirement of engineering.

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