300 KV, 6 KW POWER SUPPLY SYSTEM FOR SELF-SHIELDED LOW ENERGY DC ACCELERATOR AT RRCAT INDORE

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Abstract

A compact, low energy, self-shielded dc accelerator for industrial applications requiring beam energy in the range of 100 to 300 keV is under development at RRCAT, Indore. The power supply and control system for this accelerator is discussed here in this paper. The high voltage source is a series fed cascade generator driven by a 30 kHz sine wave inverter. Two asymmetrical cascade generators are run in parallel to enhance the current capacity of the generator. A 15-0-15 kV, 30 kHz ferrite core transformer interfaces the cascade generators with IGBT based H-bridge inverter. A buck chopper controls the dc bus voltage of the inverter so as to control the terminal voltage of the high voltage generator. A low power high frequency inverter generates the filament power supply floating at terminal voltage of the accelerator through a capacitive isolation column. Control of the filament power supply is achieved by sensing the accelerator beam current and controlling the low power inverter in a closed loop. A PC based control system designed with Lab-View 7.0 software and ADuC812 Micro-converter cards monitors and displays the various parameters of the power supply and accelerator.

INTRODUCTION

Electron beam curing is an energy efficient process, which creates unique products and improves the existing ones. It occupies less space as compared to thermal ovens and cures all the colours equally with complete removal of solvents. Radiation curable inks and coatings can be employed essentially to any substrate imaginable including paper, wood, metal, leather, vinyl, plastic, glass and magnetic tape etc. Being radiant energy the electron beam directly converts reactive liquids into solids and do not have to rely on energy-intensive evaporation system to remove solvents or water.

Electron beams are currently being used in industries for the curing and cross-linking of coatings, inks and adhesives. An energy in the range of 100 to 300 keV is useful in many applications like heat shrinkable foils and tubes, hardening of coatings, wrinkle free textiles by graft polymerisation, surface sterilization of food materials and surface hardening of plastics. Keeping these applications in focus a compact, **S**elf-shielded, **L**ow **E**nergy dc **A**ccelerator (SLEA) is being developed at RRCAT. The operating energy of the accelerator is chosen as 100 to 300 keV with maximum beam power of 6 kW. The accelerator assembly is compact and light enough to be transported and installed at the site of demonstration or application. Design features and developmental aspects of the high voltage generator, filament power supply and control system for this accelerator is described in following sections.

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HIGH VOLTAGE GENERATOR

The required accelerating voltage for this accelerator is generated using high frequency multi doubler circuits driven in parallel as shown in block schematic of Fig 1. A 30 kHz, 10 kW driver inverter feeds the power to the multiplier column through a centre-tap ferrite core high voltage transformer. A resistive voltage divider is used for measurement and control of the accelerator terminal voltage. A fast acting stabilization circuit operates the high voltage power supply either in a constant voltage or constant current mode. Both these functions can be controlled and monitored remotely through a PC that also displays the beam parameters.

For safety considerations the multiplier stack is designed for minimum stored energy. At the same time the ripple in the output voltage is kept low by selecting the high frequency operation. The power supply is short circuit protected by use of damping resistor and trip features of the chopper and inverter units. The filament power supply is generated through a capacitive isolation column, which is fed from a low power inverter. The beam current is stabilized by controlling this inverter in a closed loop with respect to emission current. The high voltage terminal of the multiplier stack is provided with a hemispherical dome and individual decks are fitted with equipotential rings so as to give electrostatic shielding to multiplier components and to control the external electric fields.

The multiplier stack embedded with high voltage divider and capacitive isolation column is fully contained in a SF_6 filled tank, which provides excellent insulation. The design aspect and constructional features of various subsystems of the high voltage generator are briefly described in following subsections.

Rectifier and Chopper Unit

The three-phase AC mains is rectified and filtered by an uncontrolled bridge rectifier and resultant DC voltage is fed to a buck-chopper, which regulates the inverter DC bus voltage in a closed loop. A half bridge IGBT module is chosen for this application where the first device is used as a chopping element and second one, with its gate-source shorted, serves as the freewheeling diode for the output stage thus reducing the size. The feedback signal for the chopper unit is derived from the terminal voltage of the HV generator through a resistive voltage divider. This means, controlling the chopper output voltage finally controls the beam energy of the accelerator.

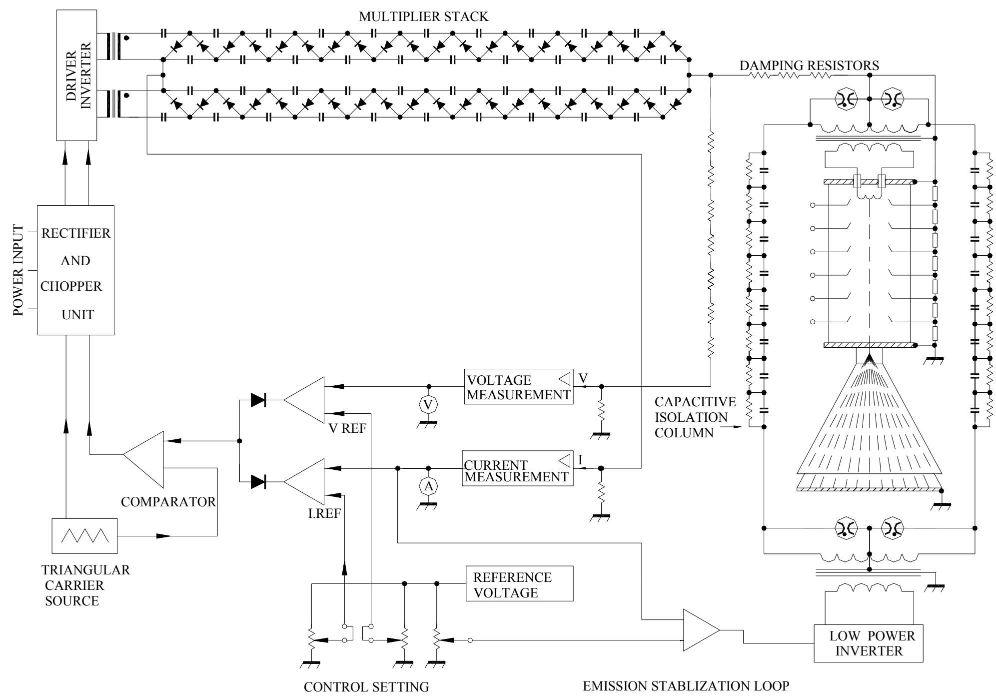

Figure 1: Block schematic of high voltage generator and filament power supply for 300 keV, 6 kW Self-shielded Low Energy DC Accelerator.

Driver Inverter

This IGBT inverter uses a high order LCLC resonant tank circuit to generate a sinusoidal voltage. For multiplier circuits a sinusoidal voltage is desired as high frequency harmonics in the square wave voltage impose high dv/dt stress resulting large peak currents in the components. A series parallel combination of LC

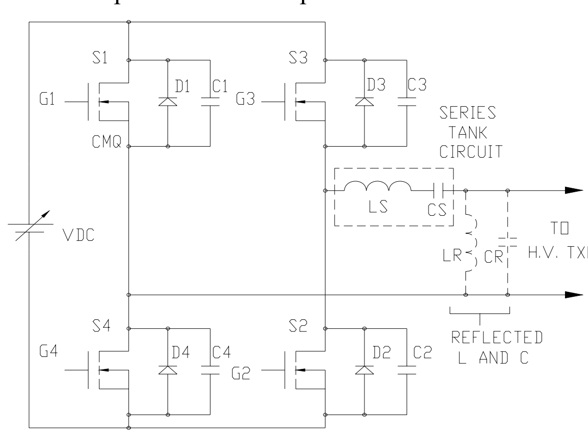

Figure 2: Schematic of the high frequency inverter.

tank circuits gives advantage of low device current and better load regulation. A full bridge topology is used for the inverter with fixed switching frequency of 30 kHz. The inverter output is controlled by controlling its DC bus voltage with the help of a buck chopper described earlier. The series arm of the LC tank circuit is tuned at 30 kHz, which filters the higher harmonics to yield a sinusoidal fundamental of 30 kHz at the output. The parallel LC tank circuit has been slightly detuned so as to limit the no-load circulating current to about 20% of the full load value. Complete discharge of the snubber capacitors has been ensured under the worst case of no load condition to maintain ZVS operation of the inverter. Thus a loss less snubber containing a capacitor of 10nF across each device has been used. Figure 2 shows schematic of the inverter.

High Voltage Transformer

The 30 kHz high voltage transformer is developed using U-93 ferrite cores. Two identical 400 V: 15 kV transformers with VA ratings of 6 kVA are made and connected in parallel. Secondary windings of the transformers are connected in series to realize a centre-tap configuration. The whole assembly is kept in oil filled tank and the high voltage terminals are brought out through Teflon bushings. Technical specifications and design parameter of individual transformers are listed below in Table 1.

Multiplier Stack Assembly

The 12-stage multiplier stack is realized using 2 kpF, 40 kV, high K, DC ceramic capacitors and 0.6 A, 30 kV, glass-passivated fast recovery avalanche diodes. Two asymmetrical voltage multiplier circuits fed from opposite phase secondary windings of the high voltage transformer run in parallel to improve upon ripple and regulation. Components of the multiplier circuits along with damping resistors are distributed and arranged over 12 circular decks of glass epoxy. Each deck assembly corresponds to a single stage of the multiplier stack and they are fitted with equipotential rings. The equipotential rings are referred to DC potentials of the respective deck. A central space of 400 mm diameter is left clear for mounting of the acceleration column. A hemispherical dome fitted at the top of the multiplier

Table 1: Transformer Specifications

Specifications/ Design Parameters	Fabrication Details
Frequency : 30 kHz	Core : U-93 Ferrite Core (three pairs)
VA Rating : 6 kVA	
Primary Voltage : 400 V	Cross section : 2340 mm^2
Sec Voltage : 15 kV	Construction : Core Type
Flux Density : 0.120 T	Cooling : Oil Natural
Mag Inductance : 1 mH	No. of Pry turns : 8
Leakage Induct. : 8 μH	No. of Sec turns : 415
Core Loss : 57 W	Pri Wdg. : Cylindrical
Cu Loss (Pry) : 8 W	Pri Conductor: Litz wire
Cu Loss (Sec) : 3.5 W	Sec Wdg. : Cross-over
Regulation : 11%	Sec Conductor: 25 SWG

Figure 3: 300 kV multiplier stack assembly

stack provides a PD free termination of the accelerating voltage. The resistive voltage divider and the capacitive isolation column for feeding power to electron gun are also accommodated in the deck assembly. Figure 3 above shows a photograph of the 300 kV multiplier stack assembly.

FILAMENT POWER SUPPLY

The accelerator uses an indirectly heated LaB_6 disc type cathode of 4mm diameter as electron emitter. A power supply of 2.5 volts and 15 amperes is required to heat the filament for its full range of emission. The filament power supply has been designed and developed with a maximum rating of 5volts and 18 amperes, using series resonant scheme at a switching frequency of 30 kHz. The injector control unit of this accelerator comprises a 200-Watts, 30 kHz fixed frequency inverter, a ferrite core step up transformer, a 12-stage capacitive isolation column and a ferrite core step down transformer. The output voltage of the inverter is stepped up through a 10 kV high voltage transformer and fed to the isolation column, which provides required DC isolation of 300 kV between the inverter and electron emitter. The AC voltage available at the top of the isolation column is stepped down and fed to the cathode heater directly. An emission stabilising circuit controls the output of the inverter in a feed back loop so as to stabilise the emission current.

CONTROL SYSTEM

A PC based control and monitoring system is employed to automate the complete operation of the accelerator. Beam energy and current are regulated in real time by control loops of the HV generator and filament power supply against their set values. The PC is used to set these values and display the read-back signals. It is also used to control the on-off operation of different power supplies and subsystems of the accelerator and display their parametric values as well as status.

The control system uses Analog Device's 8051 core based micro-converter AduC 812 chip, which has inbuilt ADCs and DACs thus reducing the over-heads for both hardware and software drastically. Each power supply and subsystem is equipped with an AduC812 based micro-converter card and they are connected to the PC through a common RS485 multidrop line. The cards act as a slave with a unique address given to them. PC acts as a master and communicates with different power supplies and subsystems through this known address. The data communication takes place through well-framed packets, which contain the address of the source and the destination, the data and the checksum byte. The software for the PC operation is written using Lab-View 7.0, which is a dedicated standard industrial software development suit.

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