HIGH POWER INDUSTRIAL ELECTRON ACCELERATOR

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Abstract

At RRCAT, we have a program of development of accelerators for Industrial applications. Under this, a 750 keV, 20 kW DC accelerator developed [1], is in operation since Nov. 2002. A 10 MeV, 10 kW electron linac is commissioned and is undergoing characterization. A 300 keV, 6 kW low energy accelerator is in advanced stage of development for curing applications. We have taken up development of a 2.5 MeV, 100 kW high power accelerator in collaboration with Budker institute of Nuclear Physics, Russia. In this paper we describe design details of the high power industrial accelerator

INTRODUCTION

The development of 2.5 MeV/ 100 kW air-core transformer type Industrial Accelerator is in progress in collaboration with Budkar Institute of Nuclear physics, Russia. Energy of the accelerator can be varied from 1 to 2.5 MeV with electron beam current up to 50 mA and maximum beam power up to 100 kW. The specifications are given in table 1. It is to be used for long term, round the clock continuous operation under industrial condition.

Table 1: Specifications of HPIA.

Operating Voltage	1 - 2.5 MeV
Max. beam Current	50 mA@ 2.0 MeV
Max. Beam Power	100 kW
Energy Dispersion	0.5 % at 2.0 MeV
Electron Gun	Indirectly heated triode electron gun with LaB_6 as emitter.
Maximum heater power	60 W
Accelerating Tube	PVA glued Accelerating tubes from BINP
HV Scheme	Air core transformer at frequency of 400-1000 Hz
Beam Scanning width	50 cm – 150 cms
Scanning frequency	50 Hz along the window and 1kHz in transverse direction.

DESCRIPTION

Figure 1 is a schematic of such an accelerator. The vessel is filled with an electrically insulating gas SF_6 and contains the primary winding, a high-voltage rectifier decks, electron gun, accelerating tube, a high- voltage electrode, and injector control unit. The elements of the vacuum unit with the output device are attached to the bottom of the vessel. The electron beam emitted by the cathode attached to the upper end of the accelerating tube is accelerated to the high voltage Uo and are transported through the beam line having vacuum pumps to the beam extraction window and is extracted into the atmosphere. The beam is scanned on the foil by X and Y scanning in order to increase the radiation field and also to distribute evenly the heat dissipated on to the foil. The irradiated material is conveyed under the beam exit window using a conveyor system.

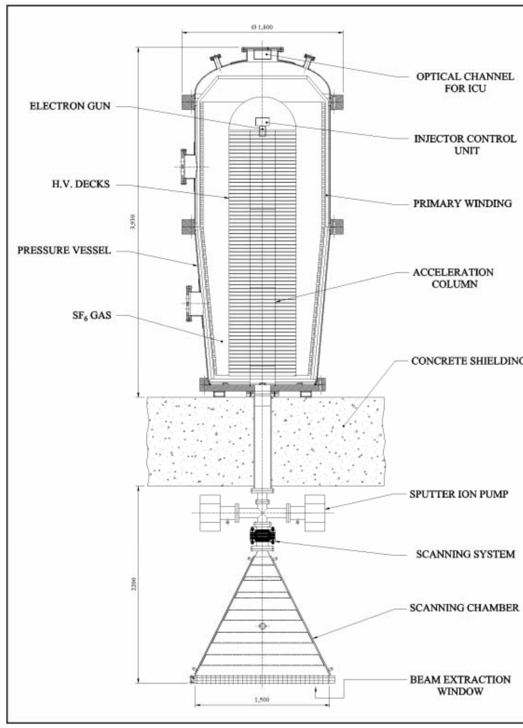


Figure 1: 2.5 MeV High Power Industrial Accelerator.

High-voltage rectifier

The HV scheme is based on Air Core Transformer (ACT), which has a water-cooled primary winding, and an epoxy molded multi-section secondary winding. Each section of the secondary winding is connected with a voltage doubler circuit and then they are stacked one upon another to build the complete high voltage column. The secondary modules are known as decks and their number in the system depends on the power supply voltage rating. Each deck generates a high voltage of 40 kilovolts and thus 64 number of such decks will be stacked in series for a total built up of 2.5 MV accelerating voltage.

The magnetic circuit consists of a tape wound yoke that surrounds the primary and secondary windings from the sides and bottom. This yoke is terminated at the top near the high voltage dome and the return magnetic path is completed through air long the center of secondary decks.

The primary winding of the air core transformer will be excited with a 400 Hz, 180 kW solid-state inverter. The accelerating voltage at the high voltage terminal will be measured by a generating type voltmeter and a low voltage divider will monitor the first deck voltage to have a cross check over any abnormal condition.

The filament heating power will be derived from a low voltage secondary deck, which will be located at the top of the high voltage column. The 400 Hz ac voltage will be rectified and controlled in a solid state chopper to yield into a current controlled dc power supply for the filament. The control of this power supply from the control console at ground potential will be accomplished by optical means. The complete power supply along with the accelerating column will be housed in a pressure vessel filled with SF_6 at high pressure. The electron energy is regulated by changing the voltage across the primary winding.

Accelerating tube

The accelerating tube is located inside the high-voltage column. Provisions for shielding the electron beam from alternating magnetic field generated by primary winding and also to shield the HV decks from overvoltage which may appear in vacuum breakdowns in the accelerating tube is available in this design. The aperture size for the accelerating tube is 100 mm, which helps in achieving good vacuum in the tube and gun. The maximum operating gradient in the accelerating tube is 1 MV per m. A focusing lens is provided in the lower end of the tube to control the beam aperture The lens current is changed according to the beam energy and is controlled automatically.

We have also successfully developed an accelerating column rated at 300 kV at RRCAT. The ceramic to metal sealing was achieved by PVA. The column was subjected to leak test after thermal and pressure cycles and no leak was found in 10^{-10} mbar-litre/s order.

Pressure vessel

. The pressure vessel is designed as per the requirements of ASME Section VIII Div.1 The specifications are given in table 2.

Table 2: Specifications of Pressure vessel.

Design pressure: Internal External	 162 psi 15 psi
Design temp.: Minimum Maximum	 20°C 60°C
Inside diameter of cylindrical portion	1500 mm 1200 mm at small conical shell
Dimension of elliptical Head	Crown radius: 1350mm Knuckle radius: 255 mm
Allowable leak rate	10^{-6} mbar-litres/sec

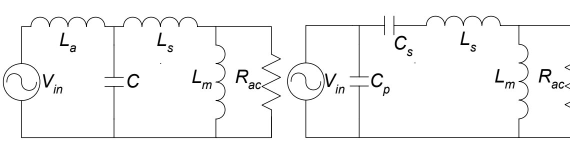
BEAM SCANNING SYSTEM

The beam scanning system consists of a scanning chamber, two scanning magnets and two sets of correction coils. The two scanning magnets scan the beam in the mutually perpendicular directions which are transverse to the beam. Each magnet has a set of correction coils to correct the position of the beam by few rads in its scanning direction. Scanning chamber is triangular in shape having dimensions of 1.5m height and 1.5m base. For beam extraction, a 50 micron thick titanium foil with a clear opening of 70mm by 1500mm is used. The window flanges are water cooled and the foil is air cooled. The side walls of the chamber are suitably reinforced to minimize the weight of the chamber.

DEVELOPMENT OF INVERTER

Compensation Scheme

As opposed to the conventional transformer, the air-core transformer has large leakage inductance (L_s) and small magnetizing inductance (L_m). Therefore, the transformer has poor regulation and draws a large reactive power from the inverter feeding the primary winding. The conventional compensation scheme, as shown in Fig. 2(a), using shunt capacitor (C) and a series inductor (L_a) can either achieve good voltage regulation or minimum reactive power depending on the operating frequency. Besides, the network uses an additional bulky inductor. Therefore, the possibility of using various other schemes is examined and a network shown in Fig. 2(b) is chosen as it offers near-unity power factor operation and nearly constant output voltage under all loading conditions. Further, it is comparatively compact, light-weight and less noisy.



(a) (b)

Figure 2: Compensation schemes for the air-core transformer. (a) Conventional, and (b) proposed.

Inverter Scheme

Various schemes are available for the development of inverter. A simple scheme named as the dual half-bridge inverter is followed. Schematic diagram of the inverter is shown in Fig. 3. Three-phase ac mains is rectified and filtered using diode bridge rectifier and LC filter (Ldc-Cdc). The filter capacitors are split and the center point is used as the return of the following inverter stage. The inverting stage uses two active switches (IGBTs S1, S2) are two diodes (D1, D2). Since active switches are not directly connected in series, the scheme is free from the shoot-through (accidental simultaneous conduction of both the switches in the same leg) which is a potential failure mode in half-bridge and full-bridge inverters. The dual half-bridge inverter can be viewed as two buck converters connected at the output through high-frequency filter inductors (Lf). Output inductor currents of two buck converters are opposite to each other, which doubles the effective output ripple frequency and reduces output ripple amplitude. In fact, there is a perfect ripple cancellation when the duty ratio of two buck converters is equal to 0.5. At this point effective output is zero. Thus zero-cross-over distortion (experienced in conventional inverters) is eliminated. Further, the paralleled inverters can be suitably phase shifted reducing input/output ripple amplitude and increasing ripple frequency. High-frequency filtering requirement (Lf- Cf) is thus reduced.

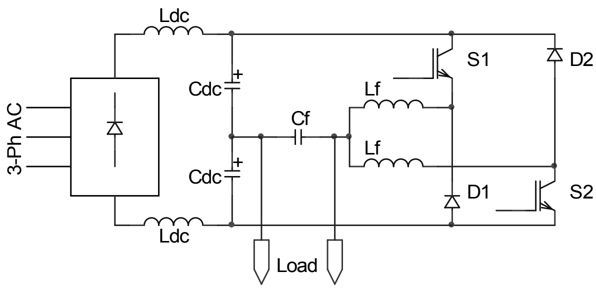


Figure 3: Schematic diagram of one inverter module.

Prototype 30 kVA Inverter

The first prototype inverter based on the dual half-bridge circuit is developed. The inverter is rated for 175 V/ 175 A rms output at 430 Hz. The IGBTs are switched at 20 kHz in sinusoidal PWM with unipolar voltage switching. Loss-less turns-off snubber is used to minimize the turn-off switching losses and stresses in the IGBTs. The module is currently tested up to 9 kVA output. Six such modules, each rated at 30 kVA, shall operate in parallel. In normal operation, when all 6 modules are healthy, each module will operate at 25 kVA. In case one module fails, rest five modules will continue to feed power to the accelerator structure without de-rating.

PC Based Control System

The PC based control and monitoring system of 2.5 MeV High Power Industrial Accelerator provides easier operation and better control and monitoring of different parameters of the accelerator and allied subsystems. The control scheme uses Analog Device's 8051 core based micro-converter AduC 812 chip. This micro-converter chip has inbuilt ADCs and DACs thus reducing drastically the over-heads for both hardware and software.

In this scheme each power supply and subsystem is equipped with a AduC812 based micro-converter card and all are connected on a common RS485 line to the PC. A RS485 to RS232 and RS232 to RS485 converter is used at subsystems and PC end. Each card will be allocated an address and will act as a slave. The PC will be the master and communicate with the power supplies and other subsystems through these known addresses. The data communication will take place through well-framed packets. Each packet will 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. The PC is used to automate the complete operation of the accelerator. It is also used to control the on-off operations or set references of different power supplies and display their parametric values as well as their status.

POTENTIAL APPLICATIONS OF 2.5 MEV / 100 KW ACCELERATORS IN INDIA

We list some of the applications of high power system:

- Sterilization e.g. urine specimen cards. 25000 cards per hour (1 MeV, 50 mA) and at 2 MeV, 20 kW this system and can sterilize disposable 2.5 ml syringes of about 100,000 per hour.
- Artificial leather for footwear production – 1.3 T/hr
- Paper pulp sheet for viscose yarn (10 kGy dose) at 50 kW power level 250 tonnes loads pulp per day.
- Grains irradiation (0.2 – 0.3 kGy). A 500 tonnes of material can be irradiated per hour with this system.
- Waste water treatment (0.4 kGy) – about 15000 M3/hr. throughput can be achieved.
- Cables – insulation thickness of 1mm to 5mm & cable outer diameter of 100mm can be cross linked using this system with a throughput of 100–1000 m/min.

In fact, in all these applications limitations will come from material handling point of view rather than the accelerator. The system can also be used in x-ray mode

CONCLUSION

The development of high power accelerator is under progress in collaboration with BINP, Novosobirsk, Russia. The equipment procured from them have been qualified and found satisfactory. Efforts are underway to interlink the equipment with indigenously developed systems e.g. Inverter, Vacuum system, extraction system, gas handling system, pressure vessel etc.

REFERENCES

[1] S.C.Bapna et.al., "Development of DC Accelerator at CAT, Indore", Invited Talk in InPAC-2005 held at Calcutta March 01 – 05, 2005.