DEVELOPMENT OF A PROTOTYPE LINEAR INDUCTION ACCELERATOR AT BARC

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Abstract

The applications of industrial accelerators span the range from plastic modifications, treatment of flu gases and medical sterilization to food processing. Pulsed electron beams and their conversion into X-rays have potential applications in the industry with the additional benefit of no residual radiations, unlike the radioactive gamma ray sources.

BARC has initiated the development of a prototype Linear Induction Accelerator (LIA) with ratings of 225kV, 5kA, 100ns, 10-100Hz. Subsequently, the energy will be enhanced to 1 MeV, by adding more cavities. The system comprises solid-state power supply using IGBTs, pulse transformers (2.5kV/20kV, 20 μs pulse and 20kV/200kV, 5 μs pulse) with cores of amorphous magnetic material and magnetic switches for pulse compression from 20μs/5μs, 1μs/250ns respectively. The induction adder consists of three cavities driven by 75kV, 100ns pulse modulator. Each cavity utilizes two toroidal cores of dimension 390/220/25mm and all of them are assembled along with oil-vacuum interface insulators in a cylindrical housing. The adder output will be applied to a field emission diode enclosed in electron gun chamber equipped with beam diagnostics. The system is in advanced stage of assembly and commissioning tests will start by the end of the year. This paper describes the detailed design and test results of various sub-systems.

INTRODUCTION

Applications like Flash X-ray radiography and high power microwave generation are unique to pulse power system because of high current pulses at kA levels. Now, pulse power systems can be designed and developed at repetition rates in kHz, thanks to the availability of saturable magnetic switches. This enhances the average power of pulse power system and thus, can make them contenders in other applications where mostly DC accelerators and gamma ray sources are in use. For comparison, it is known that a 500kW, 5MeV Linear Induction Accelerator (LIA) is approximately equivalent to a 4MCi of Co-60 source [1]. Linear Induction Accelerators can handle high currents at high efficiency, if beam transport is handled properly. Hence, before going for systems rated for high average power, our Department has taken up a project to develop a compact and repetitive pulsed electron beam accelerator.

This paper describes the design and developmental status of a prototype linear induction accelerator rated at 225keV, 5kA, 100ns, 10-100Hz. It consists of solid state power modulator using IGBTs and SCRs, pulsed transformers made of Russian amorphous core material 30kCP, magnetic switches, demineralised water capacitors for energy storage, coaxial pulse-forming line (PFL) and induction cavities. In this system, induction cavities are connected in adder configuration resulting in an output of 225 kV at the gun end. A field emission diode of suitable impedance will be used as the load for beam generation. The whole assembly will be mounted on a mobile support structure, as shown in Fig.1. Each cavity is connected by a bunch of cables to the pulsed power supply with the resultant characteristic impedance of the three bunches matching with that of the PFL. The following sections briefly describe the design of respective sub-systems.

SOLID STATE MODULATOR

This power modulator basically consists of a switch-mode power supply (SMPS) for capacitor charging followed by a command resonant charging (CRC) stage. In the SMPS, a 560V/110A DC supply is switched at 30 kHz by Eupec make IGBTs (BSM300GA120DL). This voltage is then stepped up and rectified to supply a constant current of 20A to the CRC stage, which charges a 100μF, capacitor up to 2.5 kV in 9ms. Once this capacitor is charged, charging supply is switched off for 1 ms. During this time, a thyristor (ABB make 5SPY 36L4503) of high current and high di/dt ratings is switched on with a laser trigger and this allows the first stage capacitor to discharge to the next subsystem with a peak current of 15kA. Triggering of SCR is done at 100pps. It is a compact and economic modulator design compared to that with thyratrons or spark gaps for same repeatability. This modulator is capable of giving 30kW power with energy of 250J/pulse at 100 Hz. For proper heat dissipation, devices are provided with water-cooled heat sinks. Device ratings are selected to accommodate fault currents for reliable operation.

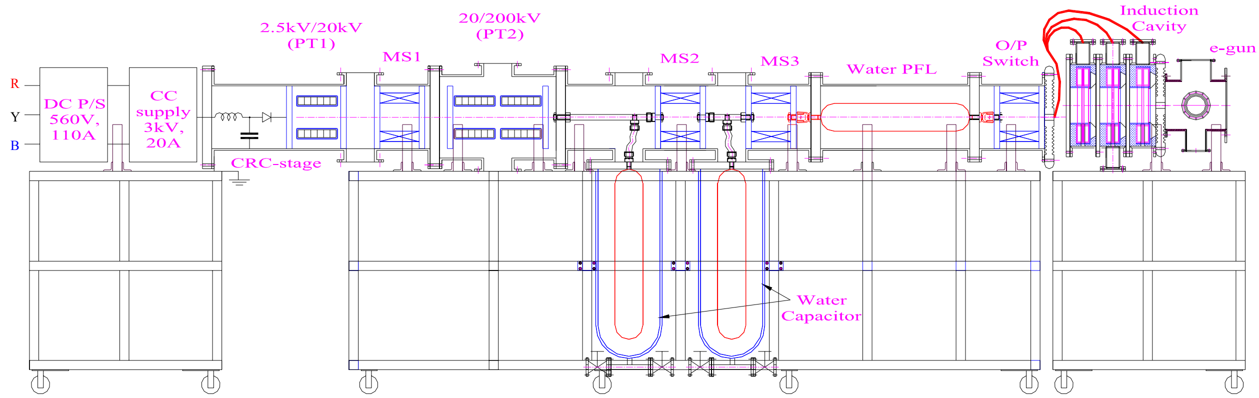

Figure 1: Schematic of Linear Induction Accelerator (200keV, 5kA, 100ns, 10-100Hz)

PULSE TRANSFORMER

An amorphous core based pulse transformer of 2.5kV/20kV, 20µs, 250J, 100pps rating has been designed using 6-toroidal cores of size 160/240/25mm. At high operating frequency (30kHz), silicon steel cores are too lossy. For high power devices, ferrite core transformers will be too bulky due to their low flux-swing. Hence, amorphous cores offering total flux swing of 3T were used for designing the transformers at operating frequency. The cores can be reset by DC, through a 3mH blocking inductor which isolates DC supply from main HV pulse. To minimize the leakage inductance, single layer winding has been done using Teflon covered copper wire of 18/19/30 size with a conducting cross-section of $0.95mm^2$ Kapton (Polyamide) tape of 2-mil thickness is provided for H.V. insulation between core and winding. Cage-type support is designed for better cooling by electrical grade Perspex (Lucite), as shown in Fig.2. Modular design based on parallel operation of 6-identical modules has been incorporated. Each module has a single-layer winding of 22 turns, each turn consisting of 11 wires, of which one is used for core-reset. A single-layer secondary of 176 turns is wound over the primary, with six layers of Kapton insulation between them. The transformer has been tested and measured parameters are in agreement with the design values. Power from the CRC stage is fed to this transformer through the SCR, which in turn charges the 1 µF capacitor on the secondary side to 20kV. This capacitor is then discharged through the magnetic switch MS1, to a water capacitor after stepping up the voltage to 200kV/5µs by means of a second pulse transformer. In this transformer, 8-cores of similar size are being included. Winding arrangement is in progress.

WATER CAPACITOR & PFL

There are two energy storage water capacitors of ratings 10nF/200kV, utilizing demineralized water of conductivity lower than 1µS/cm. It is designed to give low inductance and high energy density. The length L of the pulse forming line (PFL) depends on the velocity of propagation (c') of electromagnetic wave in the insulating medium and the desired beam pulse duration (τ). c' and L are determined from the following relations:

Velocity of propagation : $c' = c/\sqrt{\varepsilon}$ (1)

Length of line: $L = \tau . c'/2$ (2)

where, c is the velocity of light (3.10^8 m/sec) and ε_r is the relative permittivity (80 for water). The length of the capacitor is selected to match the required capacitance. Here, cooling water is made to flow from a storage tank

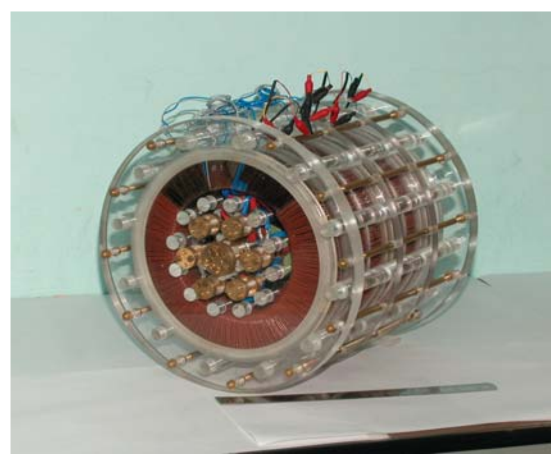

Figure 2: Amorphous core based Pulse Transformer

with heat exchanger at the rate of 45 l/min to maintain the physical and electrical properties of low-conductivity water.

MAGNETIC SWITCHES

Four magnetic switches have been designed to compress the pulse in four steps viz. (i) 20µs/5µs, 20kV; (ii) 5µs/1µs, 200kV; (iii) 1µs/250ns, 200kV; and (iv) 250ns/100ns, 200kV. Output switch consists of 8-cores in a coaxial configuration, while the first three compression

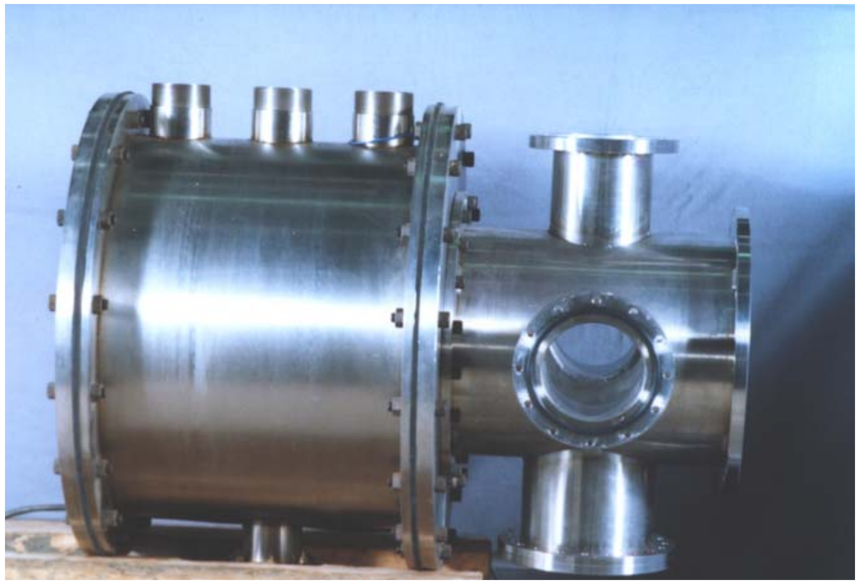

Figure 3: Three-stage Induction ADDER with gun chamber

switches have 6-cores each, with 13, 37 and 7 turns respectively. This design is based on the following formulae: [1]:

Charging time: $t_{ch}= \int v.dt /(N.\Delta B.A)$ (3)

Saturated inductance $L_{sat}= \mu_o\mu_{sat}AN^2/l$ (4)

Discharge time: $t_{dis}=\pi\sqrt{L_{sat}C_{eq}}$ (5)

where, v=instantaneous charging voltage, N=number of turns, A=core area, ΔB=total flux swing, l=magnetic path length, L_{sat}=saturated inductance, μ_o=absolute permeability ($4\pi.10^{-7}$H/m), μ_{sat}=saturated permeability, C_{eq}=equivalent capacitance, t_{dis}=discharge time. These switches have advantages of simple design, low loss and fast switching. A 200 Amp DC resets the induction cavities and the compression switches, through a blocking inductor.

INDUCTION CAVITY

The induction adder consists of three cavities driven in parallel by a 75 kV, 100 ns voltage pulse obtained from a 2.5-Ω pulse forming line. Each cavity has two amorphous cores of size: 220/390/25mm. PMMA insulators of 30 mm thickness with cylindrical surface on oil side and conical surface on the vacuum side are used at the interface. Metglas 2605CO cores of similar dimension have been used by Ashby [2] for a 750 kV, 10 kA, 60 ns LIA. The amorphous core material was tested for its pulsed characteristics in smaller samples before designing the large-core induction cells [3]. Each cavity was tested individually by a 40kV, 100ns voltage pulse from a Marx generator available with us. The system will be first tested with a $CuSO_4$ load of impedance varying from 15 Ω to 25 Ω. Depending on the results, a field emission diode with appropriate area and gap will be incorporated in the gun chamber, where vacuum of $5x10^{-7}$ mbar will be maintained, to obtain repetitive pulses without much deterioration in beam parameters.

CONCLUSIONS

Some of the subsystems like the IGBT bridge, pulse transformers, magnetic switches and induction modules have been tested individually at moderate voltages. This gives us confidence to demonstrate the operation of the whole system in the burst mode within a few months.

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