DEVELOPMENT OF A 200KEV LINEAR INDUCTION ACCELERATOR

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Abstract

Electron Linear Induction Accelerator (LIA) are for applications in high power microwaves (HPM), high gradient accelerators, flash X-rays radiography (FXR), flue gas clean-up, detoxification of chemicals, cross-linking of polymers, sterilization of food and medical waste/devices etc. The LIA-200 is being developed at APPD,BARC consists of mainly (i) solid state pulse modulator based on semiconductor devices, (ii) pulse compression and voltage amplifications stages, steps up to 200kV, 5µs and compresses these pulses to 75kV,10kA,50ns (FWHM) in five stage and (iii) three stage induction cavities in ADDER mode for relativistic electron beam generation, with matched load of 5Ω. Metglas cores have been used in transformers, switches and induction cavities. Deminearlised water capacitors and water pulse forming line have been used for low impedance energy storage and compactness. The complete system has been assembled and ready for commissioning. LIA-200 will be operated from a PLC based control system which is under testing.

INTRODUCTION

The principle of magnetic induction has often been applied to the acceleration of high-current beams in a variety of induction accelerators. The induction linac (IL) consists of a simple non resonant structure where the drive voltage is applied to an axially symmetric gap that encloses a toroidal ferromagnetic material. The change in flux in the magnetic core induces an axial electric field that provides particle acceleration. This simple non resonant (low-Q) structure acts as a single-turn transformer that can accelerate beams of hundreds of amperes to tens of kilo amperes, limited only by the drive impedance. The IL is typically a low-gradient structure that can provide acceleration fields of varying shapes and time durations from tens of nanoseconds to seve ral microseconds. The acceleration voltage available is simply given by the expression $V = A^*(dB/dt)$ Hence, for a given cross sectional area A of material, the beam pulse duration influences the energy gain. Following is th e details of LIA-200 configuration.

CIRCUIT DESCRIPTION

Fig.1 shows the photograph of the Linear Induction Accelerator and Fig.2 shows the simulated electrical equivalent circuit diagram in Orcad. Capacitor C1 is charged to 2.5kV with a constant current power supply. This is a Phase Shift Pulse Width Modulated (PS-PWM) power supply operating at 30 kHz. This topology has the capability to eliminate turn on losses and minimizes turn off losses of IGBTs present in the inverter. A Thyristor (X1) is placed to initiate the command resonance charging. T1 is a pulse transformer of 2.5kV / 20kV. L1 is the equivalent leakage inductance of the transformer T1. Diode D2 is placed to block the reverse pulses from the forward stages. Capacitor C2 gets charged to 20kV after the gate pulse to the Thyristor X1 is given. S1 is a magnetic switch to compress the pulse duration from 20µs to 5µs. Pulse transformer T2 steps up the voltage pulse of 20kV to 200kV. C3 and C4 are water capacitors of value 10nF. Magnetic switch S2 compresses the pulse from 5µs to 1µs and S3 from 1µs to 250ns. Demineralized water Pulse Forming Line (PFL), is required to get a flat topped pulse of 50ns duration at the output. Magnetic switch S4 holds the output pulse from PFL for 250ns. It gives output pulse of 50ns with sharp rise time and is applied to an induction adder cavity. Each induction cell acts as a single turn 1:1 pulse transformer in co-axial configuration.

Pulse Transformers

Amorphous core toroids based pulse transformers are designed and developed with final parameters are tabulated in table-1. Each core has outer diameter, inner diameter and hight as 240mm, 160mm and 25mm respectively. Each transformer is kept in degassed transformer oil chamber for cooling and insulation. Teflon covered wires are used for winding with kepton tape and mylar as insulating layers. Perspex flanges were used to hold the full assembly.
Chokes are designed for DC resetting of cores at 20kV and 200kV side separately.

Table 1 : Parameters of pulse transformer 1 and 2

Main Parameters	Pulse Transformer-1	Pulse Transformer-2
Turns Np/Ns	22/176, parallel 6-cores (6P)	35 x 8P/50-on all 8-cores
Voltage Vp/Vs	2.5kV/20kV, 20µs	20kV/200kV,5µs
Current Ip/Is	15kA/1.8kA	8kA/800A
Leakage L	0.55 µH	3.5µH

OPERATION OF LIA

Magnetic pulse compression is the key in achieving the output of 200kV, 50ns pulse. The operation of Induction Linac is based on series magnetic pulse compressor as reported by D.Birx [1]. Three induction cells in parallel are driven by this output pulse from PFL. It is estimated that final output pulse to cavities will be of >75kV, 5kA, 100ns FWHM [2].

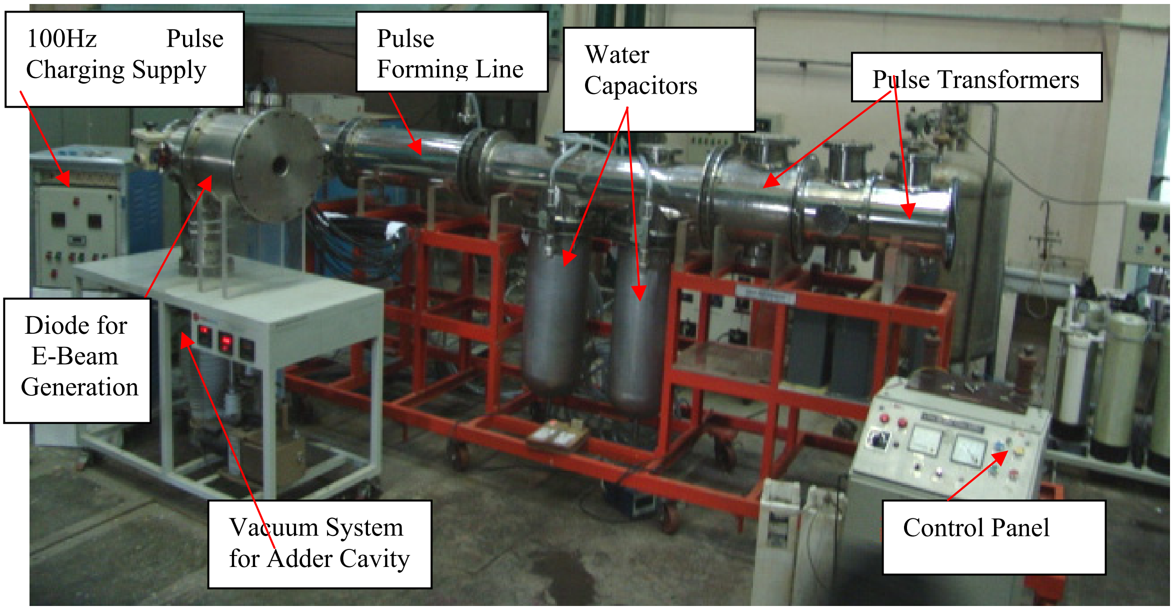

Figure 1 : Photograph of Linear Induction Accelerator

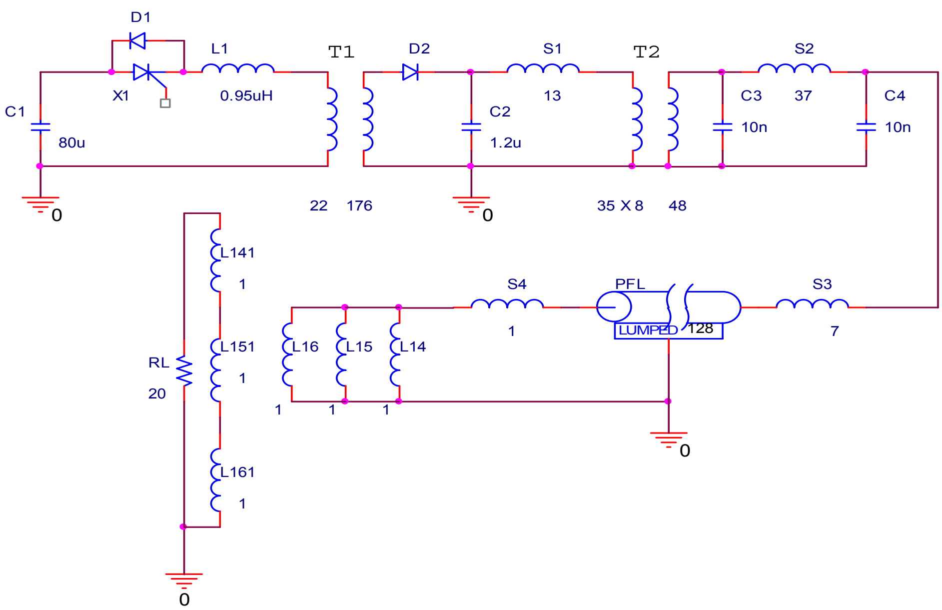

Figure 2 : Schematic showing the electrical equivalent circuit of LIA

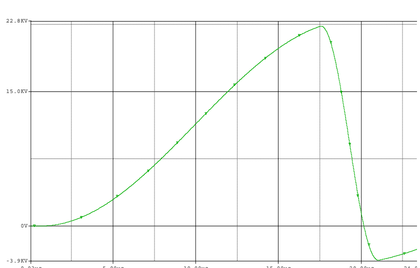

Figure 3 : Output of 20kV transformer

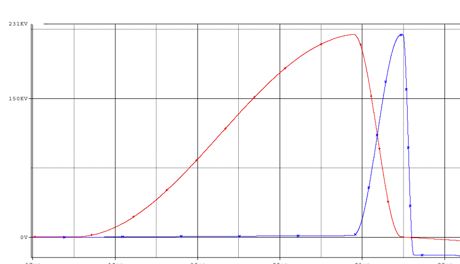

Figure 4 : Voltage across water capacitors 1& 2

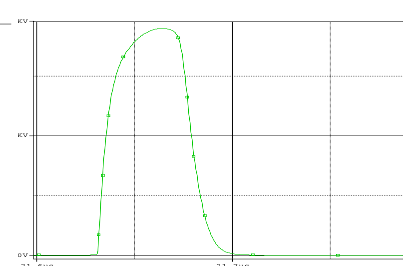

Figure 5 : Output pulse from the induction cell

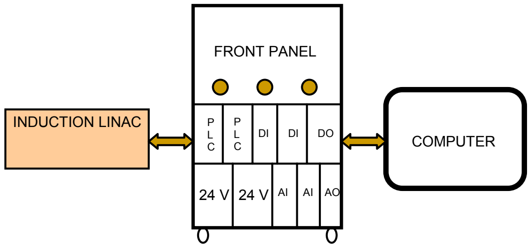

Figure 6 : Control of LIA showing front panel, PLC and data acquisition

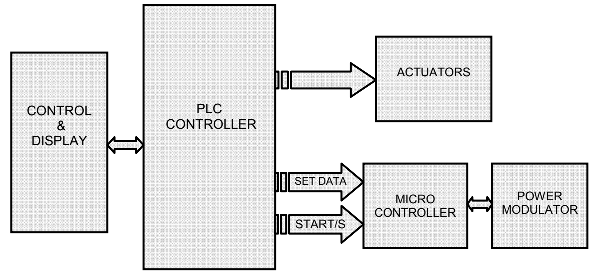

Figure 7 : Diagram showing PLC – Microcontroller interaction

ain pulse is getting reversed at the output of 20kV transformer, so that final output will be a negative pulse. Core resetting is done by applying a DC voltage in such a way that, resulted current flow should be in opposite direction to that of main pulse current [3]. Magnetic switch S1 and pulse transformers of 20kV /200 kV are reset by a 10mH blocking inductor in series with a DC supply of 0-40V/0-25A. Magnetic switches S2, S3, S4 and output induction cell are resetted by putting a reset circuit in parallel with the first water capacitor. This reset circuit consists of a blocking inductor of 10mH and current limiting resistor in series with a DC supply of 0-60V/0-60A.

SIMULATION RESULTS

OrCAD software has been used to simulate the circuit of Fig.2. Here a 3-stage induction cell is represented by three pulse transformers (L14 - L141, L15 - L151, and L16 - L161). Magnetic switch is modelled using Jiles & Atherton model and pulse forming line is modelled using a transmission line. Figure 3 shows the output of 20kV transformer charging capacitor C2. In Fig.4, the voltage across the two water capacitors are presented. Negative part of the pulse is due to oscillation with the previous stages and/or saturation of forward stage before the peak of the capacitor voltage. In Fig.5, the final output pulse, which is 280kV, 60ns has been illustrated. It is expected to get a 200kV, 100ns pulse with the experimental setup as the voltage drops with the forward stages and output switch and other stray inductances add to the duration of the pulse.

CONTROL OF LIA

For the purpose of controlling linear induction accelerator from remote position Programmable Logic Controller (PLC) based control system is used. 80C320 processor has been used for PLC system.

The PLC takes care of man-machine interaction through computer and control panel (front panel). Digital inputs from the computer or control panel (controlled manually) and from different sub-system parameters are given to PLC. Analog inputs from various sub systems are converted to 4-20mA signals and are carried to the PLC location through cables. These signals are converted to digital inputs using an Analog to Digital Converter (ADC), before being given to the PLC. The ladder logic present in the PLC processes these digital inputs and sends the required digital output through RS232 cable to microprocessor (80C535) present in the pulse modulator power supply. This microprocessor takes care of controlled DC voltage generation and triggering pulses to Thyristor. In case of any discrepancy in the process parameters like temperature rise or flow disruption, an interrupt signal goes from the PLC to the microprocessor and halts the whole system. All process parameters are sensed by the PLC as analogue and digital inputs. In EMI environment, S.S. conduits are used to shield the cables carrying various signals to PLC. These signals are filtered before being given to the PLC. PLC is encaged using thick copper strip, which is properly grounded to avoid any kind of interference. Analog signals like, oil temperature in transformer and switch chambers, water temperature at the outlet of water capacitor and PFL, water conductivity and pH, and current in the reset circuit are continuously monitored. Any variation from the preset value of these parameters will halt the system by sending the interrupt signal to the microprocessor. PLC can process 64 digital inputs and 32 analog inputs and can give a maximum of 16 analog and 96 digital outputs. Microcontroller is embedded in the power modulator. PLC will communicate to the microcontroller through RS232 for setting the charging voltage, charging current, repetition rate, number of pulses, and for sending the START/STOP signal.

CONCLUSIONS

Simulation for the induction accelerator has been performed and the results need to be checked with the experimental ones. PLC based remote control for the system was presented and it was installed at the site.

REFERENCES

[1] Danial Birx, "Induction Linear Accelerators" Physics of Particle Accelerators (AIP Conf. Proc.249) Vol.II, 1982, pp.1554-1613.

[2] Archana Sharma, S. Acharya, T.Vijayan , P. Roychoudhury & P.H. Ron, " High frequency characterization of an amorphous magnetic material and its use in induction adder configuration", IEEE-Transactions on Magnetics, vol.39,No.2, 2003, pp.1040-45.

[3] Design Report on Electron Linear Induction Accelerator (200keV, 5kA, 50ns, 10-100Hz); prepared by APPD, BARC, Mumbai, July, 2000.