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PREPRINT

THE ADVANCED TEST ACCELERATOR
A HIGH-CURRENT INDUCTION LINAC

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Introduction

The Advanced Test Accelerator (ATA) is a linear induction accelerator being built at Lawrence Livermore National Laboratory. The aim of the ATA, together with its associated physics program is the research and development necessary to resolve whether particle-beam propagation is possible. Since the accelerator is the tool needed to do the basic propagation experiment, many of its design parameters are specified by the physics. The accelerator parameters are: 50 MeV, 10 kA, 70 ns pulse width (FWHM), and a 1 kHz rep-rate during a ten-pulse burst. In addition, beam quality and pulse-to-pulse repeatability must be excellent. The unique features of the accelerator are the 10 kA beam and the 1 kHz burst frequency.

The ATA Design

The 200-m ATA facility (Figure 1)¹ has an 85-m linear accelerator and consists of four major units: the power conditioning system, the 2.5 MeV electron injector, the 190 module 47.5 MeV accelerator, and the experimental tank. The power conditioning system consists of all power supplies, capacitor banks, and pulse conditioning networks which ultimately provide the short, high-voltage pulses that drive the electron injector and accelerator modules. The injector is essentially a 2.5 MeV triode with a hollow anode through which a 10 kA electron beam is injected into the downstream accelerator sections. The beam is guided magnetically through the accelerator consisting of 190 accelerating cavities (250 kV each). The electron beam, at full energy and still magnetically guided, enters an experimental tank that contains gas of various types and pressures.

The Power Conditioning System

The power conditioning system² consists of the hardware necessary to convert the line power to the short, high-power pulses required to accelerate the electron beam. Figure 2 is a block diagram of the ATA power conditioning system.

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Power Supplies

There are ten regulated DC power supplies having a combined capacity of 2 MW. Each power supply utilizes SCR phase-control in the transformer primary to achieve 0.1% regulation. In addition to a voltage feedback circuit, there is an output current feedback loop to limit the power supply output current. The low impedance of the power-distribution pole transformers used for the power supplies also requires an additional series impedance in the primary circuit to limit fault currents when the power supply is crow-barred.

Capacitor Banks

The ATA operational parameters require the capacitor banks provide a peak power of several hundred megawatts during a burst. Each of the 21 major capacitor banks is 2000 μ f charged to 18 kV. The total energy storage capacity of all capacitor banks is in excess of 8 megajoules of which approximately 2 megajoules are delivered to the load during each burst. The capacitor banks are recharged in the 2 seconds between bursts.

Command Resonant Charge Unit

One of the more important components of the power conditioning system is the command resonant charge (CRC) units. The ultimate energy regulation of the electron beam is achieved due to the capability of this unit to resonantly charge the intermediate storage capacitor to 25 kV $\pm$.025% in less than a millisecond.

Each CRC charges the 2.5 μ f intermediate storage capacitor in each of 10 switch chassis. Referring to the simplified block diagram shown in Figure 3, CRC charging is initiated by triggering thyatron V1. The mean charge time is approximately 500 μ s with a peak current of ~1600 amps in a regulated 1 kHz burst. The usual command resonant charge circuit cannot maintain regulation on the load capacitor as the main bank voltage droops. To achieve regulation with the ATA CRCs, the technique used is known as de-queing³ or sometime resistor clipping. De-queing requires triggering V2 at some time during the charging period which essentially shorts the charging inductor and thereby

diverts the current from the switch chassis capacitor. Obviously, the trick to obtaining regulation is to be able to trigger V2 precisely at the correct time. The triggering of the de-que thyatron (V2) is controlled by the feedback circuit shown in Figure 3. The circuit, which consists primarily of a comparator and a pulse amplifier, compares the voltage waveform from a voltage divider to a precision reference. Additional compensation for the time delay resulting from the comparator, cables and the time required to trigger V2 is also required to obtain precision regulation. This compensation is accomplished by making the total time delay in the feedback circuit equal to the RC time constant of the series resistor and load capacitor and then connecting the voltage divider to the input side of the resistor. These methods have allowed better than $\pm 0.025\%$ regulation during the burst.

Switch Chassis

The switch chassis contains the $2.5 \mu\text{f}$ intermediate storage capacitor and the thyatron output switch. After the $2.5 \mu\text{f}$ capacitor is charged to 25 kV by one of the CRCs, the energy is commutated out in approximately 20 μs by six EEV CX-1538 thyratrons into a loosely coupled air-core transformer load. The six thyratrons are arranged bi-directionally such that four parallel thyratrons handle the 10 kA forward current and two handle the 5 kA inverse current.

Blumlein Assembly

The pulse power assembly (Figure 4) is a unit comprised of a 10:1 step-up transformer^{4,5}, a spark gap⁶ and a 12Ω Blumlein line. The transformer is a .6 coupled air-core transformer operating in the dual resonant mode. The switch chassis intermediate storage capacitor and the transformer primary inductance are tuned to the same resonant frequency as the transformer secondary and the Blumlein capacitance.

The spark gap is a pressurized gas-blown switch, using a mixture of N_2 and SF_6 (~7%) at 120 PSIG and flowing through the spark gap electrodes at 4cm/ms. With an adequate trigger (~150kV with $\tau_p \leq 30 \text{ ns}$) the coaxial gap exhibits a jitter $\pm 1 \text{ ns}$ during the burst. The spark gap falltime determines the risetime of the output pulse. The Blumlein is a 12Ω , coaxial,

water-filled stainless steel structure which functions as a pulse-shaping line. Blumlein output is a negative 250 kV pulse. The Blumlein drives two parallel 25Ω oil-filled cables which route the negative 250 kV pulse having a risetime of ~ 15 ns (10-90%) and a 70 ns pulse width (FWHM) to the accelerator cell.

Accelerator Cell

The basic building block of the ATA accelerator is the induction unit⁷ or accelerator cell shown in Figure 5. The drive pulse via the two oil-filled cables connects to the metal structure surrounding the 20" OD ferrite toroid. The cast epoxy insulator is the oil-vacuum interface and the electron beam centerline is through the center of the cell. Electrically, the cell may be viewed as a 1:1 transformer having a single, very tightly-coupled turn around the ferrite toroids as the primary and the electron beam as the secondary turn. The accelerating voltage is measured across the 1 inch gap, while the electron beam sees and gains energy from the axial E-field resulting from the flux swing in the ferrite toroids. ATA uses 190 of these induction cells bolted together to form its 47.5 MeV accelerator.

Injector

The electron injector (Figure 6) is a 2.5 MeV vacuum triode. The induction cells used in the injector are similar in design to those used in the accelerator with the primary differences being the larger overall dimensions. The inside diameter is larger to accommodate the re-entrant anode and cathode structure and the magnets needed to focus and guide the low-energy electron beam as it is pulled off the cathode. The anode and cathode structures confine the E-field contributions of 10 induction units into the region between anode and cathode, thereby creating the large field gradient (~ 7.5 MeV/m) necessary.

The electron beam is sourced by a cold plasma cathode and extracted by a screen grid. The cathode plasma is generated through the creation of 3,000 simultaneous surface discharges arranged uniformly over the surface of the ten inch diameter cathode. A 100 kV pulse, 10 ns in duration and individually

resistively coupled to each of the 3,000 five-mil gaps, produces these discharges. This pulse must be timed approximately 60 ns prior to the application of the grid voltage.

The grid-cathode gap is adjustable and is varied to provide an approximate 8Ω load impedance to the grid-drive pulse. The actual operating current is dictated by the particular experiment and is typically 2 to 12 kA. The grid pulse must be varied from 20 to 120 kV and accurately timed with respect to a point on the anode voltage waveform.

Non-Linear Magnetics Drive System

One of the more recent hardware developments for ATA has been the application of non-linear magnetics materials to replace a complete Blumlein assembly (transformer, spark gap and Blumlein). This has been the result of the availability of amorphous metal tape in sufficient quantities and quality to build a spark gap replacement having longer life, more reliability and better repeat performance. This development effort has led to the application of several magnetics systems on ATA, and has also resolved the questions concerning jitter and simultaneous operation of multiple magnetics systems.⁹ While these magnetics drivers each have their own applications, the fundamental operation is the same, so a discussion of any one system is representative.

The magnetic grid driver system is a three-stage cascading magnetic switch. Each stage uses a 30 kg Metglas 2605 CO core to provide a power gain of ~ 4 in transferring the electrical energy between capacitors of equal value and then finally into the grid cathode 8Ω impedance. As seen in the schematic Figure 7, the final stage capacitor is a 1.5Ω water-filled PFL. The output pulse energy is initially stored in a $2.65\ \mu\text{f}$ capacitor located in the "switch chassis" schematically illustrated in Figure 8. The bias resistor located in the magnetic switch provides rapid reset of the saturable magnetic cores between pulses and biases the cores so as to provide the maximum ΔB swing available.

The grid driver output has a risetime of ~ 30 ns (10-90%) and is 50 ns FWHM. To meet the more rigid injector requirements on pulse risetime, a pulse sharpener is placed in the transmission lines which connect the grid driver and injector. The prototype grid driver is currently being used on the Experimental Test Accelerator (ETA) also at LLNL. All the magnetics systems have met or exceeded their design performance parameters, and they have also shown the reliability, long life and the capability for operation at higher repetition-rates that will be required for an ATA upgrade.

ATA Current Status

ATA was originally scheduled for completion in October 1982. As of mid-October the check-out procedure of the injector had begun with first injector beam extraction slated for the end of October. At that time, final check-out of the accelerator modules begins, and will continue for several months at which point the first full energy beam experiments can begin.

ATA Future Status

While the propagation experiments will dominate the future useage, the accelerator's high-beam quality and high current lends itself to other experiments. Changes in the accelerator performance would probably be the result of widespread implementation of non-linear magnetics system throughout the machine.

References/Footnotes

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Figure 1

Sketch of the ATA facility showing arrangement of major components: the pulsed-power network, the electron injector, the accelerator, and the shielded, gas-filled experiment tank. (Many of the vertical elements forming the pulsed-power network have been omitted for simplicity.) This whole assemblage will be 200 m long. The cross-section of the accelerator shows the end of one accelerator cavity, located in an underground tunnel, as well as the Blumleins connecting it to the pulsed-power transformers above ground.

Power Conditioning System

Figure 2

CRC Voltage Regulation System

Figure 3

ATA PULSE POWER UNIT ASSEMBLY

Figure 4

250kV INDUCTION CELL

Figure 5

ATA 2.5MeV ELECTRON INJECTOR

Figure 6

MAGNETIC GRID DRIVER

Figure 7

SWITCH CHASSIS SCHEMATIC

Figure 8