THE ADVANCED TEST ACCELERATOR (ATA), A 50-MeV, 10-kA INDUCTION LINAC*

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Abstract

The ATA is an induction accelerator designed to produce 70 ns pulses of electrons at currents of 10 kA and energies in excess of 50 MeV. The accelerator is capable of operating at an average rate of 5 Hz or at 1 kHz for ten pulses. The parameters were chosen primarily to provide the experimental basis for advancing the understanding of electron beam propagation physics. The 85 m accelerator has been under construction for the past four years and has adopted mainly an improved version of the ETA technology to satisfy the required parameters. Initial operation of the facility and the energy conversion system from primary power to axial electric field will be described; recent advances in magnetic switching which have been incorporated in the injector will also be discussed.

Introduction

The Lawrence Livermore National Laboratory has been performing research in the field of charged particle beam technology for a number of years. The Advanced Test Accelerator (ATA) is a new high current induction accelerator constructed by LLNL for research in the physics of intense self-focused electron beams. It will be the major facility for basic research not only in beam propagation but other experiments requiring a high-quality, high-intensity electron beam. In selecting the accelerator design, the philosophy of the ATA staff has been to minimize the risks involved in achieving the required beam parameters by concentrating on the most thoroughly developed high intensity particle accelerator technologies. The induction linear accelerator was the obvious choice from this standpoint. The 5 MeV ETA which was operational at the time, provided a base from which all ATA subsystems evolved. Although this technology based on gas blown spark gaps provided satisfactory experimental operation, it was clear that the 50 MeV ATA would require considerable improvements in both performance and reliability.

Summary of Project Milestones

Authorization to initiate the A-E selection was received in February of 1979 and the contract was awarded that summer. Construction of the conventional facility was started in the summer of 1980 and building occupancy took place one year later.(Fig.1&2) Fabrication of the electrical and mechanical systems went on concurrently with facility construction and installation of those systems was started in the fall of 1981. A new injector was added to the scope of construction so that ETA could continue valuable experiments uninterrupted. (Originally the ETA injector was to be used on the ATA).

In March of 1980, the realization of the ATA size and complexity prompted a re-evaluation of the controls and diagnostics. The result was to implement a minimum hybrid system of conventional controls and an expanded computer control and data retrieval system. The new injector was completed on schedule and tests were initiated in November of 1982. The remaining accelerator was completed earlier this month. (Fig. 3)

The ATA Design

The induction accelerator was the obvious choice for satisfying the ATA parameters of 50 MeV, 10 kA, 70 ns pulse width, and a 1 KHz rep-rate during a ten pulse burst. The complete facility is about 200 m. long and consists of the control room with support facilities, 2.5 MeV Injector, 47.5 MeV accelerator and the experimental area. All of the power conditioning systems and pulse forming networks are housed directly above the accelerator and the energy is fed to the accelerator cells in the tunnel by means of semi-flexible oil filled cables. (Fig. 3&7) The drive system for the accelerator is designed to provide twice the energy required by the beam allowing flexibility for output currents and voltages in excess of the design parameters.

Injector System

The details of this system are covered in paper W11 of this conference but for continuity's sake a brief description is included here. The electron injector is basically a 2.5 MeV, 10 kA triode. It consists of ten induction cells added together each supplying 250-300 kV. The cells are very similar in design to those used in the accelerator with the primary difference being the larger overall dimensions (Fig. 6). The inside diameter is larger to accomodate the re-entrant anode and cathode structure housing the magnets needed to shape and guide the electron beam. The re-entrant structures concentrate the E-field into a small region creating the required high field of 12.5 MV/m. The electron beam source is a cold plasma cathode and extraction is done by mean of screen grid about 2 cm (adjustable) from the cathode. The cathode plasma is generated by creating 3,000 simultaneous discharges arranged uniformly over the surface of a 25 cm diameter printed curcuit board. A high voltage pulse variable from 20-100 KV in amplitude and with duration from 20-100 ns is resistively coupled to each of the 5 mil gaps producing the discharges. This pulse is normally timed from 20 to 100 ns ahead of the grid voltage pulse.

The actual operating current and voltage levels are dictated by the particular experiment but typically they fall in the ranges of 2-12 kA and 2-3 MV respectively. The grid pulse is supplied by a magnetic pulse generator and is also variable from 50-150 kV.

The Accelerator

The 2.5 MeV electron beam is guided for 85 m by focusing solenoids and steering magnets through 190 accelerating modules each supplying 250 kV for an additional energy gain of 47.5 MeV.

The Power Conditioning System

The power conditioning system consists of the hardware necessary to convert the line power to the short, high-power pulses required to accelerate the

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electron beam. Figure 8 is a block diagram of the ATA power conditioning system.

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 crowbarred.

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 μF charged to 18 kV. The total energy storage capacity of all capacitor banks is in excess of 8 megajoules of which approximately 1 megajoule is 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 μF intermediate storage capacitor in each of 10 switch chassis. Referring to the simplified block diagram shown in Figure 4 & 8, CRC charging is initiated by triggering thyratron V1. The mean charge time is approximately 500 μs 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-queing or sometime resistor clipping. Dequeing 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 thyratron (V2) is controlled by the feed-back circuit. 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 μF intermediate storage capacitor and the thyratron output switch. After the 2.5 μF 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 5kA inverse current.

Blumlein Assembly

The pulse power assembly (Figure 5 & 9) is a unit comprised of a 10:1 step-up transformer, a spark gap and a 12 Ω Blumlein line. The transformer is a 0.6 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(6%)at 120 PSIG and flowing through the spark gap electrodes at 4cm/ms. With an adequate trigger ($\sim$-150kV with $T_r \simeq$ 20 ns) the coaxial gap exhibits a jitter $\pm$ 1 ns during the burst. The spark gap falltime determines the risetime of the output pulse. The Blumlein is a 12 Ω, 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 24 Ω 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 unit or accelerator cell shown in Figure 11. The drive pulse via the two oil-filled cables connects to the metal structure surrounding the 20" OD ferrite toroid. The porcelain 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 core 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. The cells are assembled in six modules of five cell units and 16 modules of ten cell units for a total of 190 cells.(Fig. 10) The major differences between the ETA and the ATA cells are the added ferrite pieces on the feed points, on the back plane and the wave matching corner changes. These changes help to suppress the beam breakup modes that could lead to beam instability.

Magnetics Drive Systems

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 rep-rate performance. This development effort has led to the application of three magnetic systems on the ATA as grid, master trigger, and igniter pulsers. While these magnetics drivers each have their own applications, the fundamental operation is the same. These magnetic pulse compressors have allowed versatility in machine timing by decoupling their respective systems from the high pressure gas blowers. This subject is covered thoroughly in paper J3 of this conference.

The Trigger System

In order to impart the proper energy to the beam pulse it is crucial that the voltage pulse applied to the acceleration cell coincide with the arrival of the head of the electron beam cluster. Accurate timing is achieved by proper cable lengths in the spark gap trigger system and by ensuring that the spark gap jitter is less than ± 1ns. The first trigger Blumlein is arranged to accept a pulse command from the master trigger in a fan out of ten to one until all spark gaps are supplied with a -150 kV trigger pulse. The trigger system utilizes Belden YR 19456 as the pulse distribution coaxial cable and all connectors are of LLNL design.

Instrumentation and Control

The ATA instrumentation and control system basic function is to provide to the operator via displays and touch panels interfaces to all major subsystems at different levels of abstraction. It consists of dual DEC VAX 11/750 minicomputers, five DEC LSI 11/23 microprocessors, six Modicon 584 programmable controller (PC) systems and CAMAC data acquisition system. The computers and programmable controllers are organized as dual hierachial network. The function of the minicomputer is to act as operator interface, make high level decisions, and do data archival and retrieval. The microprocessors are the interface between the minicomputer and the PC's. The PC, with its remote I/O structure, is the interface between the computer and the equipment. The PC's are used to collect data, effect control commands, and make low level decisions. The operator interface to the control system is through a color graphics system for information display, transparent touch panels, digital knobs and a few switches for command inputs. Some of the simple controls for power conditioning systems is directly controlled through hardware.

Vacuum System

The vacuum system consists of 3 turbo pumps and 28 cryopumps spaced along the length of the accelerator at the intercell junction and are capable of producing a total pumping speed of 56,000 liters per second. In the design of the vacuum system careful consideration was given to the current carrying interior contours at the pumping stations to minimize discontinuities which can produce high order mode excitation by the beam pulse.

Fluid Systems

High purity water is used as the dielectric medium for the last stage of energy storage, the Blumlein. Because of the high voltage gradients, the water is filtered, de-ionized, degassed and has a resistivity of 18 MΩ-cm. Circulating oil in the accelerator cells and the high voltage transmission lines provides both cooling for the compensation resistors and high voltage insulation. Standard low conductivity water is used for cooling of all other electrical and mechanical systems.

Initial Operation

Pulse power tests were begun in October and Injector characterization began during off-shift hours in November and continued intermittently through mid-January of 1983. The voltage and current waveforms are shown in Figure 12. Tests of the first 10 MeV began on March 1. Full current and voltage parameters will be attempted after beam characterization at lower currents is complete.

The voltage parameter in both the injector and accelerator cells has been exceeded by 20% and full current has been extracted from the injector. The pulse characteristics are as expected: 70 ns FWHM with 50 ns flat-top and the 10-90% risetime is 15 ns. The spark gap jitter has been within the ± 1 ns even without trigger optimization. At the present time the accelerator is controlled through a combination of manual knobs and the Programmable Controller. A considerable amount of work is yet to be done before the full computer control is implemented. Checkout and optimization will continue for several months before full energy experiments can begin.

Overall the accelerator performance has been excellent. While the propagation experiments will dominate the future usage, the accelerator's high beam quality lends itself to other experiments as well. We find ourselves in a fortunate situation that if future experiments dictate cw operation or a 10 kHz burst, the existing magnetic prototype which has compiled in excess of 10^7 shots could be implemented quite rapidly throughout the machine.

Acknowledgements

The ATA construction cycled through the typical phases of a project more than once but at the end all adversities were overcome. As in any project it is impossible to justly acknowledge all the participants; in particular those deserving special recognition should take pride in the accomplishment. The rapid construction would not have been possible without the excellent support and cooperation that was received from many sections of this Laboratory, LBL, NSWC, and DARPA. We are indebted to Dan Birx for the significant improvement made by replacing the master trigger, igniter, and grid spark gap systems with magnetic ones. A partial list of the ATA staff which was directed in their effort by the theoretical and experimental physics teams are listed below.

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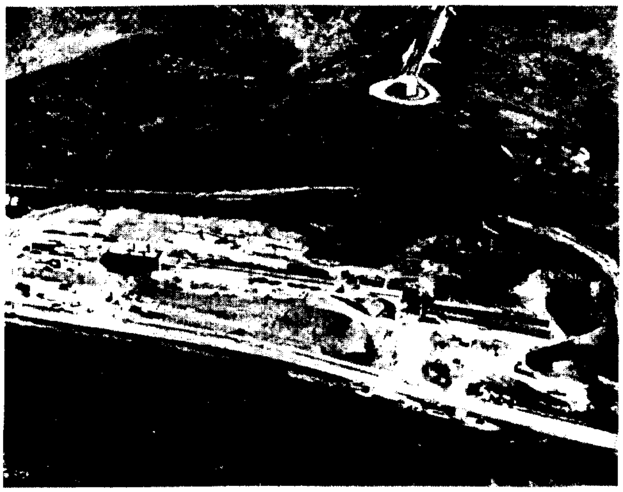


Fig. 1

Fig. 4

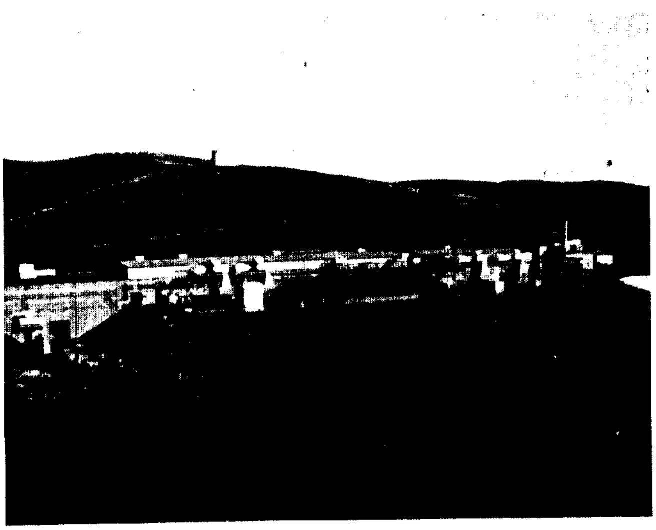


Fig. 2

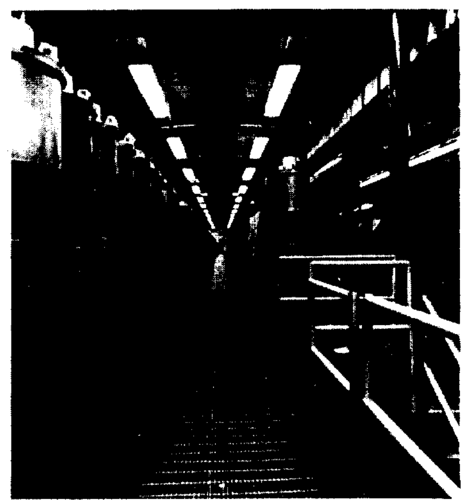


Fig. 5

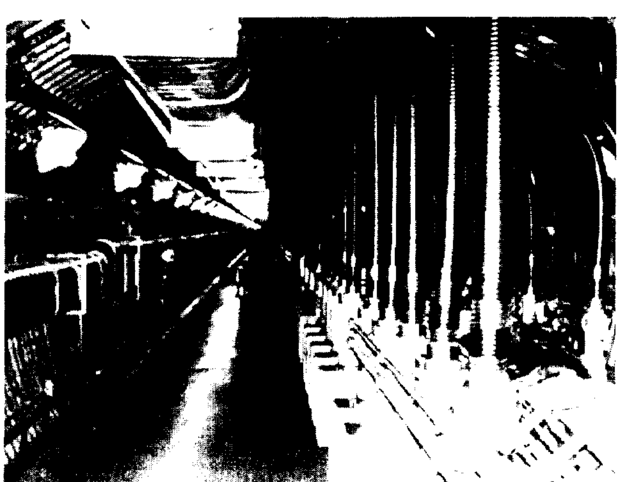
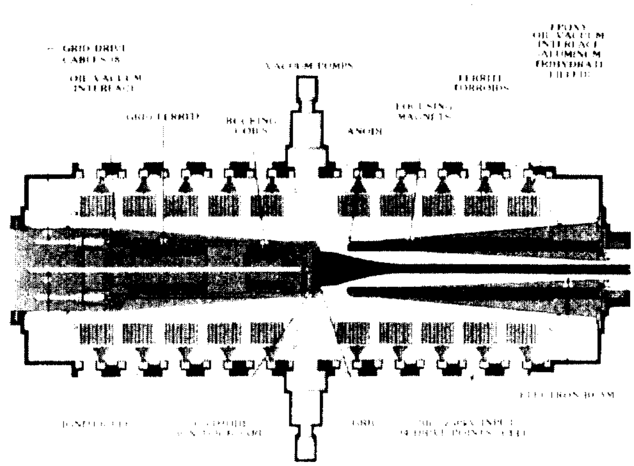


Fig. 3



ATA 2.5MeV ELECTRON INJECTOR
Fig. 6

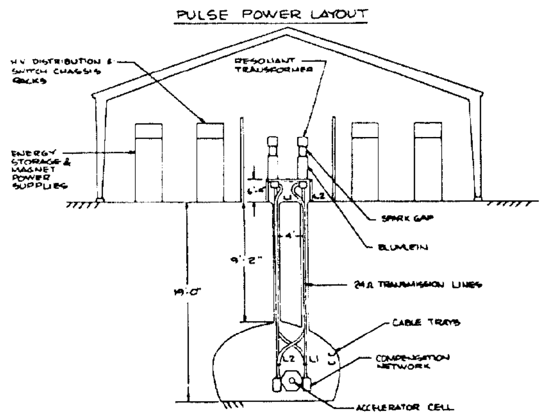


Fig. 7

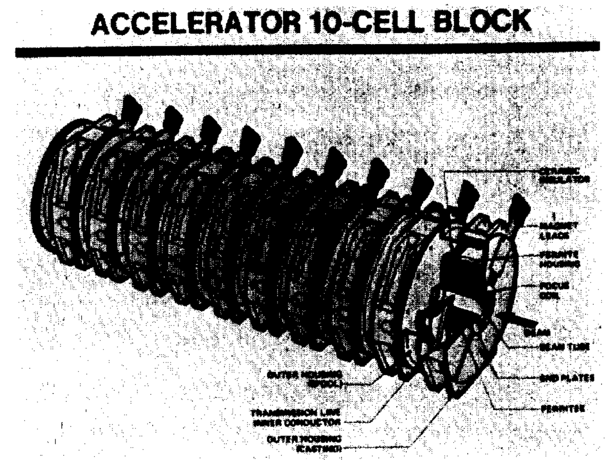


Fig. 10

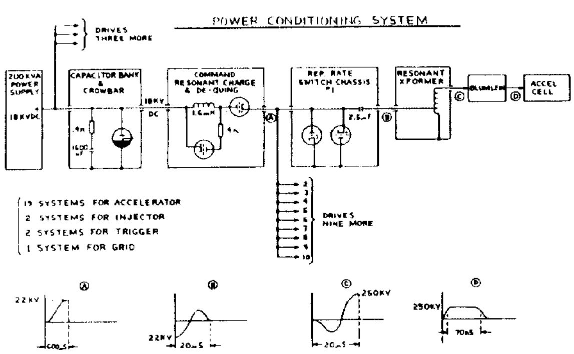
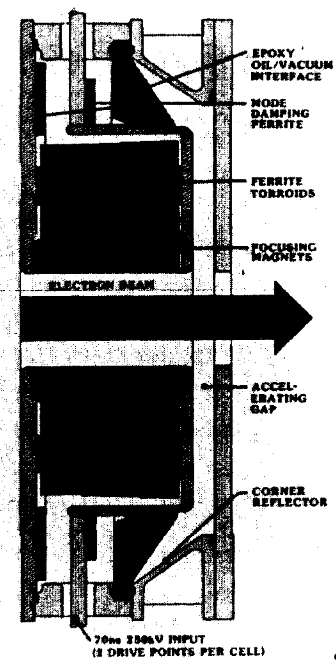
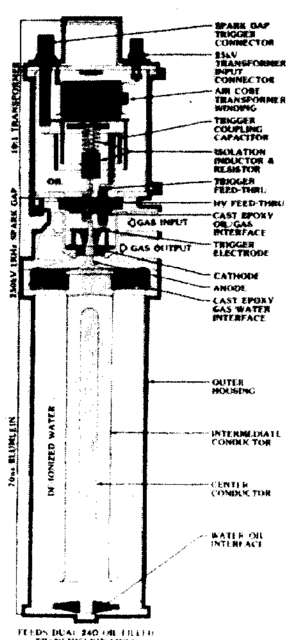


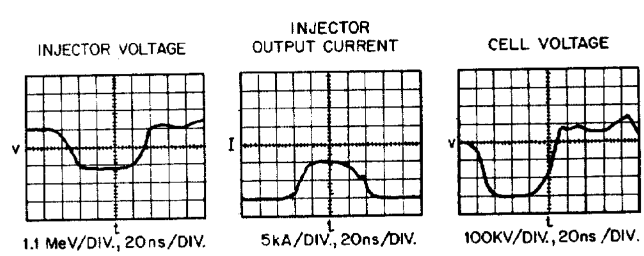
Fig. 8



ATA 250kV INDUCTION CELL
Fig. 11



ATA PULSE POWER UNIT ASSEMBLY
Fig. 9



10 PULSE OVERLAYS OF ATA
INJECTOR CURRENT AND VOLTAGE
Fig. 12