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"ADVANCED TEST ACCELERATOR (ATA) PULSE POWER TECHNOLOGY DEVELOPMENT"*

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Abstract

The Advanced Test Accelerator (ATA) is a pulsed linear induction accelerator with the following design parameters: 50 MeV, 10 kA, 70 ns, and 1 kHz in a ten-pulse burst. Acceleration is accomplished by means of 190 ferrite-loaded cells, each capable of maintaining a 250 kV voltage pulse for 70 ns across a 1-inch gap. The unique characteristic of this machine is its 1 kHz burst mode capability at very high currents. This paper describes the pulse power development program which used the Experimental Test Accelerator (ETA) technology as a starting base.[1] Considerable changes have been made both electrically and mechanically in the pulse power components with special consideration being given to the design to achieve higher reliability. A prototype module which incorporates all the pulse power components has been built and tested for millions of shots. Prototype components and test results are described.

Introduction

The ATA is presently under construction with an expected completion date of October, 1982. The ETA has served as a base of technology development for all the major ATA components. Although there are many similarities to the ETA,[6] many changes have been made to achieve better performance and higher reliability. The series fire mode for the pulse power has been adopted in place of the parallel mode; that is, a single switch chassis is fired ten times at a 1 kHz rate rather than ten parallel chassis fired sequentially to obtain a burst. The resonant transformer has been redesigned with a coupling coefficient of 0.6 and the Blumlein impedence has been increased in favor of longer pulse length. The spark gap has been redesigned to fit the larger diameter and lower gradient Blumlein. Oil filled cables have been used to carry the pulse to the accelerator cell rather than rigid water-filled transmission lines. The prototype of the pulse power components has been operational for about one year and over seven million shots have been accumulated with very good results. The design of all major components has been completed and the majority of the components are in the procurement cycle.

Charging System

The resonant charging system was adopted for the ATA because it requires fewer active components to achieve a ten pulse burst. However, much of the cost saving of going to the serial rep-rate system is offset by additional cost of the command resonant charge system and energy storage banks. The serial system should be much more reliable, particularly from the standpoint of thyratron interaction. A further added advantage of the system is the ability of obtaining more than ten pulses with minor modifications. A block diagram of the pulse power system is shown in Figure 1.

Including the trigger system and the grid drive, there are 25 energy storage and resonant charge units. The basic system consists of a 2000 μf capacitor bank charged to 18 KVDC and a resonant charge unit using 10 English Electric Valve CX1538 thyratrons, the same type as used in the switch chassis. A schematic of the resonant charging system is shown in Figure 2. This unit charges 10 switch chassis, each with 2.5 μf capacitor, to 25 kV. Charging is initiated by triggering V1 and when the proper voltage is reached, V2 is triggered to terminate the charge cycle. During the ten pulse burst, the voltage on the capacitor bank will droop about 3 kV, but the pulse to pulse voltage regulation on C1 will be held to 0.1% or 25 volts. To achieve this regulation, the control chassis corrects for the voltage drop across the isolation resistor and uses the rate of change of the charge voltage to account for the finite delay in triggering V2 and the drooping voltage on the capacitor bank. Six parallel CX1538 are used for V1 to keep the same RMS current per tube as that in the switch chassis thyratrons. On the basis of peak current, four parallel thyratrons are used for V2. The RMS current in V2 was maintained within limits over the required range of rep-rates by the proper selection of R2. Note that lower rep-rates raise the RMS current in V2 since less of the coil energy commutates into C1. The energy storage banks and crowbar are of a standard design and utilize 50 μf, 18 kV capacitors from General Electric.

Resonant Transformer and Switch Chassis

The pulse forming network that provides the 70 ns pulse is a water-filled Blumlein. The impedance of the line is 12Ω and this corresponds to a 14 nf capacitance. The Blumlein is charged to 250 kV from the 2.5 μf, 25 kV capacitor. The step-up to 250 kV is obtained by discharging the capacitor into an air core transformer with a coupling coefficient of 0.6 and a voltage gain of ten to one. The resonant transformer has a total charging time of 20 μs and lends itself nicely to a 1 kHz rep-rate mode. This dual resonance transformer (Figure 3) with the primary and secondary tuned to the same frequency yields optimum conditions for energy transfer.[2] At the peak of the secondary voltage, the primary voltage and current and the secondary current are all zero resulting in almost all of the energy being transferred to the Blumlein. An additional benefit of this charging mode is that spark gap recovery time is enhanced as there is no energy remaining in

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the transformer to maintain the arc.

The dual resonance transformer requires a bilateral current switch in the primary circuit. The primary switching requirements of 10 kA at 25 kV were met with specially developed thyratrons from EEV, the CX1538, for both forward and inverse directions. The inverse thyratrons are triggered from the zero crossing of the output current and in case of prefire all thyratrons are self triggered to insure current sharing. The recovery time of the switch chassis after a Blumlein discharge has been measured at 15-20 μs. This is actually an adequate recovery time for higher rep-rates than the 1 kHz burst mode design. The 2.5 μf capacitor was designed for longlife with 80% voltage reversal and was supplied by Aerovox.

Spark Gap and Blumlein

The 12Ω Blumlein consists of water-filled coaxial cylinders with an outer diameter of 18" and an overall length of about 48". The voltage stresses were chosen conservatively to allow for Blumlein ringing without breakdown in case of spark gap misfire. The water is continuously circulated at 4 GPM and constantly being degassed, deionized and filtered to maintain a resistivity of 18 MΩ - cm. The Blumlein couples to the high pressure spark gap through a cast epoxy insulator. The spark gap has undergone redesign in order to adapt to the larger diameter Blumlein (Figure 4). The new design has reduced inductance and improved output pulse risetime. The electrode geometry and spacing are essentially the same as the ETA's. The coaxial trigger electrode is designed to wear in the axial direction with no changes in the electrical characteristics thereby resulting in long life. The trigger electrode is normally biased at the mid-potential of the charging pulse and a negative going trigger pulse of 225 kV initiates the spark gap closure. Standard deviation in time jitter of less than 1 ns have been achieved for a one thousand pulse sample. A gas mixture of 8% SF_6 and 92% N_2 at 120 psig is circulated through the gap electrodes with a velocity of 5 cm/ms. This combination of gas parameters has yielded burst-mode rep-rates in excess of 1 kHz at full voltage.

Accelerator Cell and Transmission Lines

The accelerator cell is essentially identical to the ETA's.[4] Assembled into a block of ten cell units, each cell contains seven TDK-PE11B ferrite cores about 10" ID, 20" OD and 1" thick (Figure 5). Self reset for these cores is obtained during the Blumlein charging cycle. One major electrical difference between the ETA and the ATA cells is the added ferrite pieces on the feed points, on the back plane and the wave matching corner changes. These changes suppress the beam breakup modes[5] eliminating the need for higher level pulsed magnetic fields to insure beam stability. The output voltage pulse at the accelerator cell gap is shown in Figure 6.

Two 4" OD oil filled flexible lines of 24Ω each provide the matching impedance from the Blumlein to the cell. These transmission lines have been pulsed to over 500 kV before a breakdown occurs. A nice feature of these lines is that even after voltage breakdown has occurred at high levels, operation at 250 kV is unimpaired. These lines also serve as oil return lines from the cell to the power conditioning building.

Prototype Test Results

The ATA consists of a 2.5 MeV injector and 47.5 MeV accelerator. Each pulse power unit supplies 250 kV so that 190 units are required for the accelerator and 20 for the injector. The same pulse power unit is also used to supply the trigger to ten spark gaps. The pulse power units are housed in a 300' building about 19' above the tunnel housing the accelerator cells (Figure 7). Because of the large number, very high reliability was designed into each unit. A complete pulse power system has been operational for about one year and all design parameters have been achieved or exceeded. Over 7 million shots have been accumulated during the test. The accelerator cell and insulator show no signs of arcing or breakdown even with a large number of shots at 350 kV level. The 24Ω cables have been arced intentionally many times by overvoltage, but recovery has always occurred and operation at 250 kV has been unimpaired during the test. For a fraction of the test, the Blumlein has been tested in the ringing mode to 300 kV by overpressurizing the spark gap. A few breakdowns occurred with no visible damage. The full spark gap parameters of rep-rate, jitter and rise time have been achieved. The housing design has been frozen, but the electrode materials are still under study since we have not achieved the desired life. The resonant transformer has shown a few minor corona problems which have been corrected. Since the oil in the transformer is not circulated, the housing incorporates a cooling system and a rubber expansion chamber to allow for temperature variations. The switch chassis thyratron have operated without failures or deterioration. It is projected that thyratron life will be in excess of 10^8 shots. Test stand operation will continue to research electrode materials and to better define component life.

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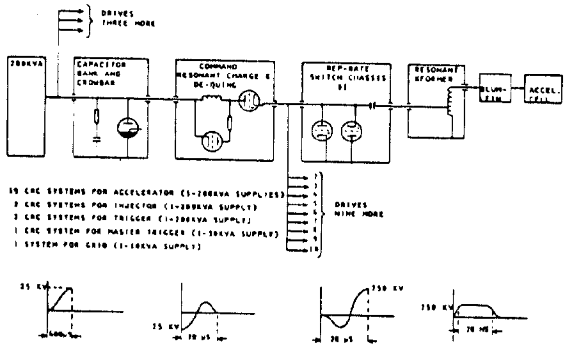


FIGURE 1 PULSE POWER CONDITIONING SYSTEM

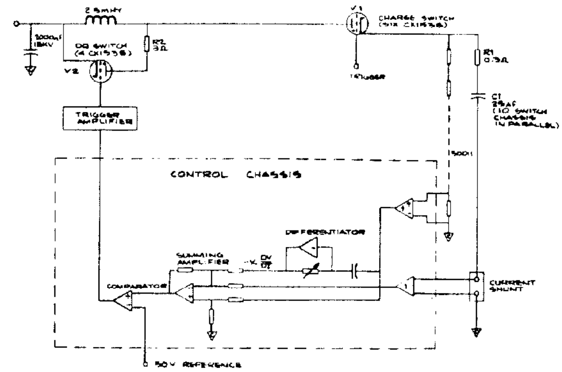


FIGURE 2 COMMAND RESONANT CHARGE SYSTEM

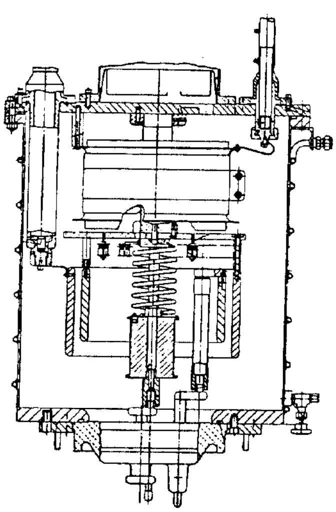


FIGURE 3 RESONANT CHARGING TRANSFORMER

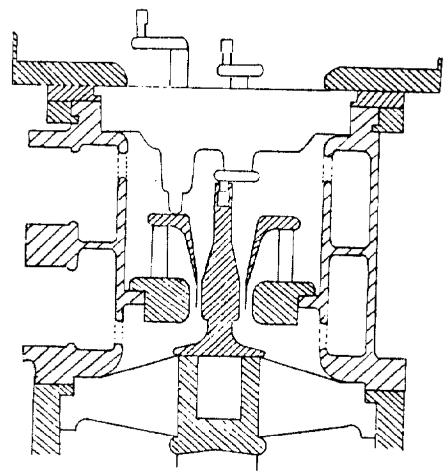


FIGURE 4 SPARK GAP

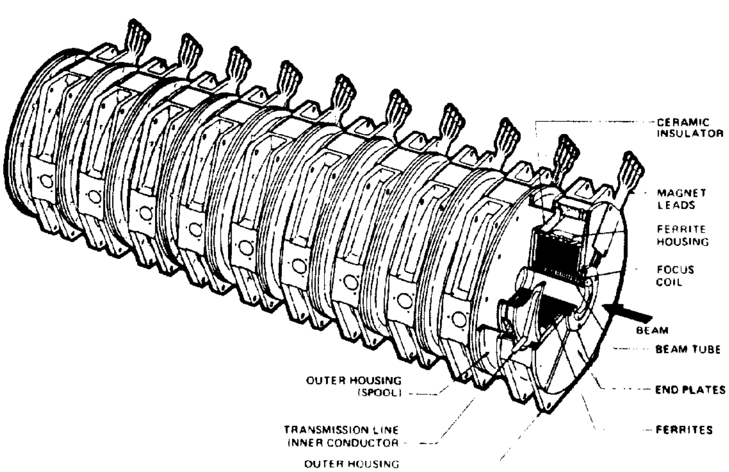
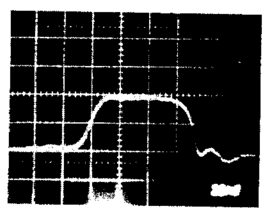


FIGURE 5 ACCELERATOR TEN CELL UNIT



TR = 18 NS (10 - 90%)

FLAT TOP = 50 NS

FWHM = 70 NS

VOLTAGE = 250 KV

FIGURE 6 ACCELERATOR CELL VOLTAGE

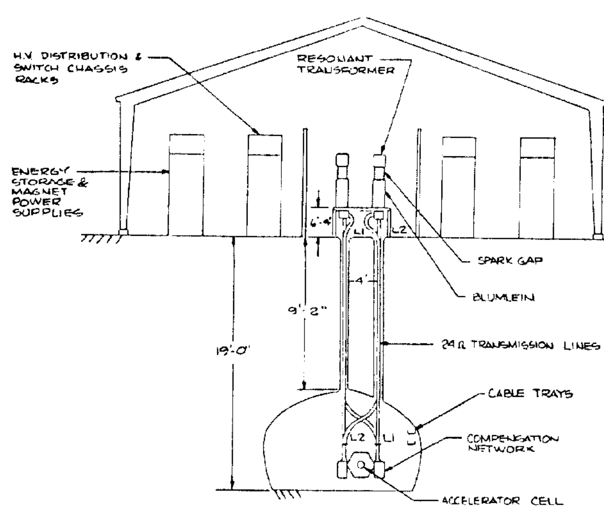


FIGURE 7 PULSE POWER LAYOUT