conf. 790327--74

MASTER

PREPRINT UCRL- 82448

Lawrence Livermore Laboratory

THE EXPERIMENTAL TEST ACCELERATOR (ETA)

Ross E. Hester, Donald G. Bubp, John C. Clark, Alfred W. Chesterman,
Edward G. Cook, Warren L. Dexter, Thomas J. Fessenden, Louis L. Reginato,
Ted T. Yokota, Andris A. Faltens

March 27, 1979

THIS PAPER WAS PREPARED FOR SUBMISSION TO
Particle Accelerator Conference, held in San Francisco, Calif.,
March 12-14, 1979.

THE EXPERIMENTAL TEST ACCELERATOR (ETA)

Ross E. Hester, Donald G. Bubp, John C. Clark, Alfred W. Chesterman, Edward G. Cook, Warren L. Dexter, Thomas J. Fessenden, Louis L. Reginato, Ted T. Yokota*, Andris A. Faltens**

Abstract

The Lawrence Livermore Laboratory is constructing an induction linac with the following parameters 10kA, 50ns FWHM pulse width, 5MeV, and 5PPS. This paper describes the design features of the 2.5MeV injector and it's associated pulsed power systems.

A 10-kA, 2.5-MeV, 50-ns FWHM pulse-width electron gun has been designed as an injector for a 5 MeV accelerator. It has a "burst" mode capability of 5 pulses in sequence spaced 1 ms apart, or it can be operated at 5 pps. When operating in the burst mode, the time-averaged repetition rate remains at 5/s.

The accelerator is of the induction variety in which a toroidal ferromagnetic material (ferrite) is coupled to pulsed high-voltage modules, generating an axial accelerating electric field. The 2.5-MeV gun consists of 10 0.25-MeV induction units. The most unusual parameter is the beam current, which has led to some special design considerations. The prospect of possible accelerator instabilities has led to a choice of high-voltage induction units similar to those in the LBL ERA[1] accelerator rather than those used in the Astron design.[2,3] This reduces the number of accelerator structures that can interact with the electron beam. The high current also requires a relatively high-voltage gun (2.5 MeV), because potential depression due to space charge fields can lead to serious beam transport problems if the gun energy is too low. An approximation for the limiting current for a electron beam in cylindrical conductor is $I \simeq \frac{17(\gamma^{2/3}-1)^{3/2}}{1+2\ln\frac{b}{a}}$ kA

where γ = beam energy in rest mass units and b/a is the ratio of pipe to beam diameters

(eg. for $\frac{b}{a} = 2$, $\gamma = 6$, $I = 24.8kA$).

Figure 1 is a schematic cross section of the electron gun. The electron source is a 25-cm-diam oxide cathode heated by a tungsten wire filament. We chose an oxide cathode because of the desire to have a highly reproducible electron source. Experience with the Astron accelerator[2] had shown the feasibility of oxide cathodes and demonstrated the pulse-to-pulse reproducibility of these cathodes. The cathode operates at a temperature of 850°C. An 85-kV pulse applied between the cathode and a grid spaced 1.5 cm from the cathode extracts the required current from the cathode. The grid voltage is supplied by a small high-voltage pulser and is independently controlled. The extractor grid is required to prevent formation of a hollow beam. The grid structure shorts out any radial electric field in the plane of the grid and imposes a uniform longitudinal electric field gradient at the cathode surface.

Gun designs that involve lower current levels (e.g. Astron) would normally have a grid at the anode plane. This gun must use a hollow anode. The beam current and resulting B_Θ field are so large that a grid in the anode region (shorting the E_r field component) would result in a catastrophically overfocused beam.

A solenoidal focus coil is built into the anode structure. The large diameter of this coil allows the magnetic field to extend longitudinally back to the cathode and provides sufficient focusing to prevent space-charge blowup of the beam. A bucking coil behind the cathode prevents any B_z field from threading the cathode. This is necessary to avoid net angular momentum in the beam when it leaves the solenoidal beam transport.

The dimensions of the gun were determined by two factors. We wished to limit emission from the oxide cathode to 25 a/cm^2. Our tests indicated long cathode life would be possible at this level. The other factor is voltage-holding, both along insulators and in vacuum gaps. The short pulse length is of great value in voltage-holding, but the design for a high repetition rate machine must be more conservative than for single shot operation. These considerations led to the design shown in Fig. 1.

The beam dynamics calculations were made with EGQ, a code designed specifically for this task.

As Fig. 1 shows, the gun is constructed in two parts. Two large ceramic accelerating columns are each divided into 10 increments that are resistively graded to insure proper voltage distribution. Five 250-kV induction units in series provide the voltage for each accelerating column. The accelerating columns serve as the barrier between the vacuum and the oil dielectric that fills the induction units. The division of the gun into two parts accomplishes several things. It provides a vacuum pumping port in the center of the gun, partially shields the insulators from the electron beam, and makes assembly easier. Figure 2 is a photograph of the gun taken from the rear. The appendages on the side are the pulsed power units, Blumleins, spark gaps, pulse transformers and transmission lines.

The power conditioning diagram for the 2.5 MeV ETA gun is shown in Fig. 3. The primary power system must supply the beam energy as well as the intentional losses in the compensation network, losses in ferrite and the switching system. Past experience has shown that in order to achieve a stable and repeatable beam pulse, a 0.1% or better regulation is necessary for the pulse power system. The high degree of regulation is provided by a hard tube modulator in series with the main charging supply. The modulator tailors the charging voltage to the primary capacitors which deliver the burst energy. These capacitors are sequentially discharged at the desired rep-rate by a thyratron switch into a ten-to-one step-up transformer resonantly charging the Blumlein. The Blumlein energy is delivered to the ten series ferrite loaded cavities by means of a coaxial air blown sparkgap.

Modulator and Power Supply

The basic modulator[4] design is the same as for the Astron Accelerator. The mode of operation has been changed from the command resonance charging to constant current operation. Each of five modulators provides a voltage ramp for charging 116 μF to 20 kV in 200 ms.

Switch Chassis, Resonant Transformer and Blumlein

The accelerating potential of 250 kV at 40 ns duration is delivered from a Blumlein by a shorting switch (spark gap). The pulse

*Lawrence Livermore Laboratory, Livermore, California
**Lawrence Berkeley Laboratory, Berkeley, California

conditioning components are shown in Fig. 4. They consist of a 3 μF capacitor discharged by a dual FX 2508 thyratron into the primary of a step-up transformer which charges the Blumlein.

The Blumlein[5] is a 10Ω water line. The low impedance geometry is necessary as the pulse network delivers over 60% of the stored energy to dummy load and compensation network. The choice of water as the dielectric permits the construction of high energy density networks. Water has the added advantage of being able to recover from a breakdown without having formed conducting by-products. However, water does require a circulation system to remove dissolved gases and conducting ions. By selecting a 15" outer diameter pipe the voltage gradients were limited to 100kV/cm. All surfaces at the high gradient points are radiused and electropolished. The Blumlein components are constructed of stainless steel which is less likely to suffer surface damage in the event of a breakdown. The energy stored per Blumlein (~300 joules) is marginally safe for surface damage.

The design of a charging transformer of the Blumlein is influenced by the load, the switch, step-up and charge time. The load is the Blumlein capacitance, about 10 nF. The switch for the transformer is a FX2508 thyratron capable of 6 kA peak current at 25 kV. The use of this thyratron imposed a further constraint for a non-reversing current unless costly auxiliary circuits such as diodes are utilized. Based upon the thyratron capabilities and limitations, the transformer is required to have a minimum step-up of ten-to-one and a non-reversing current of 10 kA. The 10 kA is predicted upon the use of two parallel thyratron, operating at 5 kA each, for which ample testing in the millions of shots existed.

Since the load is capacitive, a resonant charging transformer is logical. The most commonly used transformer of this type has a coefficeint of coupling K = .6. This yields energy transfer efficiencies over 90%. Unfortunately, this requires a bidirectional switch. After a thorough circuit analysis, the computer generated curves showed that a particular set of transformer parameters did indeed satisfy all the requirements. The voltage and current waveforms in Fig. 5 correspond to a coupling coefficient K = .525 and a ratio of primary to secondary frequency ratio of .69. These waveforms show that the current in the primary is non-reversing and near zero at the secondary voltage peak. The primary voltage has actually reversed 60% at this time, but this energy remains in the capacitor since the thyratron opens at the zero current point. Although this case is not optimum from an energy transfer standpoint, the remaining energy has no adverse effects on the spark gap recovery time and does satisfy the step-up and primary current requirements. Other components in the transformer are mid-potential biasing for the trigger electrode and a coupling capacitor for the spark gap trigger. Varistors provide damping and an inductor provides isolation for high frequencies.

Spark Gap Design

The spark gap bolts on to the lower end of the Blumlein line and switches (shorts) the mid conductor to ground[6]. The coaxial cylindrical geometry was adopted for two main reasons: long life and high rep-rate. The trigger electrode is expected to wear uniformly in the axial direction with no change in the electrical characteristics resulting in tens of millions of shots before replacement. The coaxial geometry further assures high gas velocities and low pressure drop to achieve the 1 kHz burst rate. The chamber on the outside of the spark gap reduces the pressure drop and provides uniform gas flow through it. The interface insulators were made of polycarbonate resin because of their strength. The trigger electrode and sparking area for anode and cathode are made of tantalum for easy replacement after wear.

The 1 kHz burst rate was achieved with a mixture of 6-8% SF_6 and Nitrogen flowing at about 4 cm/ms. The gage pressure for full voltage operation is about 100 psi. With the spark gap running at about 75% of self break, the jitter was in the few nanosecond range and the rise time was 12 ns. The 120 kV trigger for the twenty gun spark gaps is obtained from two Blumlein lines with ten outputs distributed by high voltage cables.

HV Induction Units

The total 2.5 MeV gun voltage is obtained by stacking ten accelerating cavities (250 kV each) in tandem. Because of the reentrant structure of the gun, the ferrite cores had to be manufactured in twelve segments glued in pairs to form a toroid .96 m I.D. and 1.28 m O.D. The gap at the joints was less than .04 mm. The ferrite segments were PE11B supplied by TDK. Eight such segments maintain the required 250 kV for 50 ns on the accelerating gap. The total flux swing from this ferrite[7] is about 5 KG with a coercive force of about .25 Oersted. The accelerating cavity is filled with oil which is outgassed and filtered.

References

1. The ERA 4 MeV Injector Avery etc., 1971 Particle Accelerator Conference, Accelerator Engineering and Technology, March 1-3, 197, IEEE Trans. Nucl. Sci., 18 (1971).
2. "High Current Linear Induction Accelerator for Electrons," Rev. Sci. Inst., 35, 886 (1964).
3. J. Beal, N. Christofilos, and R. Hester, "The Astron Linear Induction Accelerator," 1969 Particle Accelerator Conference, March 5-6, 1969 (also UCRL-71405).
4. D. Rogers, W. Dexter, A. Myers, L. Reginato, A. Zimmerman, "Modulator Charging System Upgrade for a 5-MeV Electron Accelerator", IEEE 1978 Thirteenth Pulse Power Modulator Symposium
5. E. Cook, L. Reginato, "Off-Resonance Transformer Charging for 250-kV Water Blumlein", IEEE 1978 Thirteenth Pulse Power Modulator Symposium
6. A. Faltens, L. Reginato, R. Hester, E. Cook, A. Chesterman, T. Yokota, W. Dexter, "High-Repetition-Rate Burst-Mode Spark Gap", IEEE 1978 Thirteenth Pulse Power Modulator Symposium
7. International Magnetics Conference

Acknowledgment

This work is jointly performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore Laboratory under contract number !'-7405-Eng-48 and ARPA Order No. 3718.

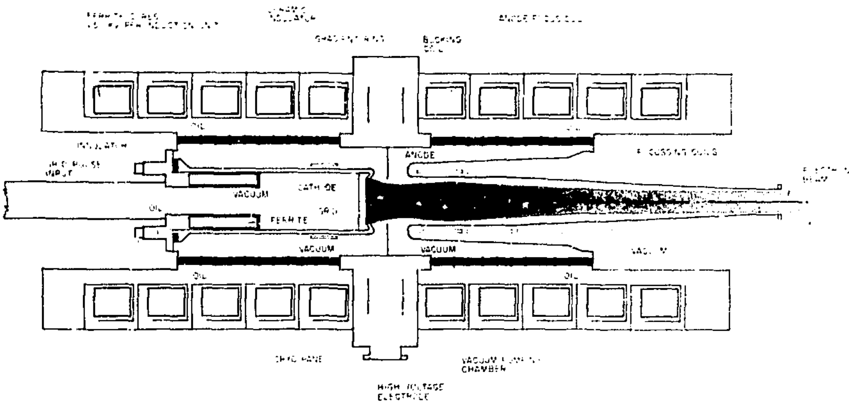

Fig. 1 - Cross Section of 2.5 MeV, 10 kA Electron Injector

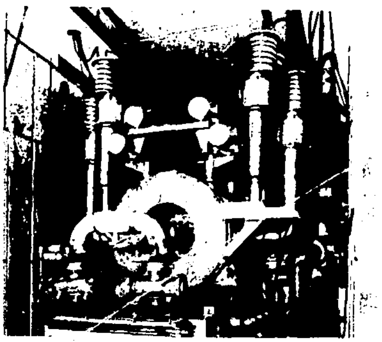

Fig. 2 - Cathode End of Electron Injector

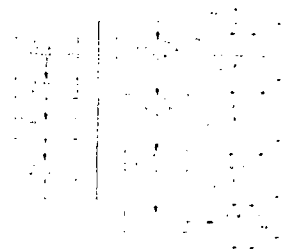

Fig. 3 - Power Conditioning Diagram

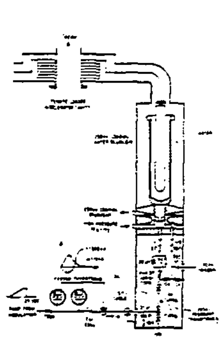

Fig. 4 - Pulse Power Conditioning Components

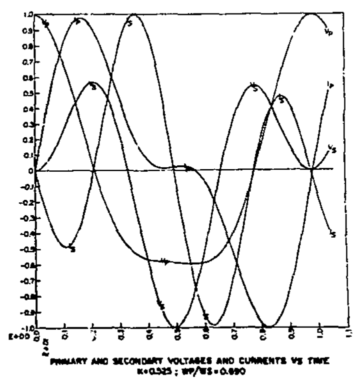

Fig. 5