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SUBNANOSECOND TRIGGER SYSTEM FOR ETA

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Summary

A high-voltage trigger system capable of triggering 30, 250 kV spark gaps; each with less than ± 1 ns jitter has been constructed. In addition to low jitter rates, the trigger system must be capable of deliverying the high voltage pulses to the spark gaps either simultaneously or sequentially as determined by other system requirements. The trigger system consists of several stages of pulse amplification culminating in 160 kV pulses having 30 ns risetime. The trigger system is described and test data provided.

Introduction

The Experimental Test Accelerator (ETA) is a 5 MeV, 10 kA linear induction accelerator. The accelerator has a five pulse burst at 1 kHz capability and a maximum average repetition rate of 5 pps. The ETA can be divided into two subsections; the injector and the accelerator. The injector is the source of the 40 ns electron beam and provides the first 2.5 MeV of accelerating potential. The accelerator consists of ten induction accelerating cells spaced along the beamline, each of which increases the beam energy by an additional 250 kV.

The source of the accelerating voltage is a water filled 10.5 Ω Blumlein charged to 250 kV. The energy stored in each Blumlein is delivered to the induction cells by triggering the Blumlein spark gap.

Each of the ten induction units (250 kV each) within the injector, is driven by two Blumleins. All the injector spark gaps must be triggered simultaneously with a jitter of less than $\pm$ 1 ns in order to generate the proper accelerating waveforms and potential.

The accelerating voltage must be present across the accelerator induction units when the electron beam propagates down the beam tube so the ten accelerator spark gaps are triggered sequentially. The jitter requirement for the accelerator spark gaps are the same as the injector's.

Trigger Requirements

Before a trigger system can be developed, the characteristics of the spark gap and its associated coupling and bias circuits must be understood. As seen in Figure 1, the ETA spark gap is a coaxial switch having three concentric tantalum electrodes which are the anode, trigger, and cathode.[1] The trigger electrode is positioned at the electric field mid-potential and in addition is biased to the Blumlein half voltage point by a resistive divider. As seen in the spark gap trigger circuit schematic in Figure 2, the negative trigger pulse is capacitively coupled to the trigger electrode. The coupling capacitor ($\sim$ 100 pF) and the stray capacitance ($\sim$ 30 pF) of the trigger electrode to the anode and cathode (ground) form a voltage divider which couples approximately 75% of the trigger pulse to the trigger electrode.

Testing of the prototype ETA spark gap established a set of trigger parameters which provided satisfactory triggering. The testing indicated a minimum trigger pulse of 160 kV (at the drive side of the coupling capacitor) with a 10-90% risetime not to exceed 30 ns is required. These trigger levels are for a Blumlein charge voltage of 250 kV; less trigger voltage is needed as smaller charge levels. A gas mixture of nitrogen and 6-8% SF_6 is used in all spark gap jitter measurements. The maximum operating gas pressure is 120 psi and th gas flow rate thru the spark gap is approximately 5 cm/ms.

Trigger System

Trigger Blumlein

The number of triggers needed led to the concept of using standard ETA water Blumleins as trigger sources. The risetime of the Blumlein output pulse at < 20 ns 10-90% is adequate. In addition, the low source impedance (10.5Ω) enables a single Blumlein to drive several 55 Ω (nominal impedance) cables simultaneously. The limitation to the number of cables that may be driven by a single Blumlein is a function of the impressed cable drive voltage. Since the Blumlein output risetime is less than the required cable's electrical length, voltage doubling occurs at the spark gap end of the cable and the drive voltage need be only about 80 kV. This requires an attenuator between the Blumlein and trigger cables but this allows the number of trigger cables to increase since the overall parallel cable impedance can be less than 10Ω . For convenience and versatility, each trigger Blumlein drives ten trigger cables. This arrangement requires two trigger Blumleins for the injector and one for the accelerator, but provides the flexibility of independent control. The output of a trigger Blumlein and the corresponding trigger voltage on the spark gap side of the coupling capacitor are shown in Figures 3a and 3b respectively. The 10-90% risetime of both signals is <20 ns.

Of course, the trigger Blumleins also require fast low-jitter triggers. These triggers are best provided by another Blumlein. This Blumlein, the master trigger, must have its output attenuated to match into the trigger cables. Jitter in the master trigger Blumlein is not as critical since all machine timing sequences are initiated by its output pulse, however, other physics constraints necessitate a consistent master trigger pulse.

Spark Gap Trigger Transformer

The master trigger spark gap requires a trigger pulse which satisfies the trigger parameters. This trigger pulse is supplied by a special transformer. The transformer used is built on the same principles as the induction accelerator cells. This is an application of magnetic induction (Faraday's Law). In the cross-section of the transformer as seen in Figure 4, each of the nine ferrite toroids is supported in a metal can which forms a single turn around the ferrite. When driven by a voltage pulse the resulting flux swing in the ferrite induces a voltage into the metal rod in the center of the transformer. In this manner each of the ferrite toroids represents a 1:1 transformer and the output of the transformer is simply the sum of the voltages across the individual 1:1 transformers. The result is a 9:1 step-up transformer having a risetime approximately equal to the risetime of the individual voltage drives to the transformer inputs.

When filled with transformer oil the internal dimensions of this transformer approximately a 50Ω impedance to match into the drive cable and minimize reflections. The drive impedance to each of the nine sections of the transformer is 5.0Ω ($\sim$50 Ω/9). The drive for each section is a 0.5 μF capacitor switched into the drive cables with a thyratron. Both the capacitor and thyratron are built into a low inductance housing to minimize risetime. The capacitor is resonantly charged.

The transformers output pulse width is primarily dependent upon the available volt-seconds of the ferrite. The ferrite (Stackpole 7D-B) is chosen to have sufficient cross-sectional area such that a DC or pulsed reset is not required to ensure the required output pulse width. Since the transformer drives an open circuit (spark gap coupling capacitor), the output pulse oscillates and thereby keeps the ferrite from remaining in saturation. The transformer output pulse into the spark gap is shown in the oscillogram in Figure 5.

A simplified schematic of the overall trigger system is shown in Figure 6. The trigger sequence is started just prior to the Blumleins being fully charged. A low level trigger signal passes through an amplifier which in turn triggers the nine thyratrons to the trigger transformer. The trigger transformer triggers the master trigger Blumlein spark gap. At this time all timing control is lost; all further spark gap trigger pulses are automatic. The cable lengths between the master trigger, the two injector trigger Blumleins, and the accelerator trigger Blumleins determine the respective timing between injector and accelerator since propagation delays through the Blumleins and spark gaps are varied to delay trigger pulse arrival times between spark gaps on the accelrator for sequential triggering. All trigger cables from injector trigger Blumleins to injector spark gaps are the same length.

Measurements and Results

Measurements of spark gap jitter are made on two different systems. Initial measurements were taken on the test spark which is triggered by a trigger transformer having a risetime of only 100 ns. Later measurements are recorded from the trigger, injector, and accelerator spark gaps which are triggered by the faster risetime Blumlein source. In both cases, a digital time interval counter having a time resolution of 0.1 ns is used. The time interval counter measurements are initiated by a signal taken from the spark gap trigger pulse and terminated by the attenuated Blumlein output pulse. Propagation delays through the Blumlein and cables are constant so the jitter is the difference between measurements. For large numbers of measurements, the jitter is simply the deviation around the mean.

The measurements on the test spark gap were extensive[2]. The parameters varied included spark gap voltage, trigger pulse amplitude, gas pressure and gas mixture. Jitter distributions based on approximately one hundred measurements were tabulated and plotted for each operating point. While the trigger pulse was not optimum, these measurements established the operating conditions and limits of the spark gap, the gas system, and the trigger system.

Jitter data for the trigger, injector, and accelerator spark gaps is generated while the ETA machine is being pulsed. Jitter measurements recorded for the trigger Blumleins, injector and accelertor spark gaps are relative to the master trigger. A minimum of one hundred data points are recorded for a given operating condition. The jitter information is presented in two formats - an actual plotting of the jitter distribution about a normalized mean and in terms of the standard deviation around the mean.

The jitter data for one of the injector trigger Blumleins is shown in Figure 7. This spark gap operating at near optimum conditions exhibited a σ_{ITB} of 0.85 ns (one standard deviation). The output of the trigger Blumlein triggers the spark gap having the jitter distribution shown in Figure 8. The total deviation with respect to the master trigger and including the jitter of the injector trigger Blumlein is 1.27 ns. Using the relationship $\sigma^2 Total = \sigma^2 ITB + \sigma^2 IB$, one standard deviation for the injector spark gap is 0.94 ns. These distributions are representative of all injector and accelerator spark gaps operating under the same conditions.

In the burst mode of operation jitter data is more difficult to obtain. A relative measure of overall system jitter is made by examining an overlay of the burst pulses Figure 9 is a 5 pulse overlay of the sum of the injector accelerating voltages.

Conclusion

We have built a trigger which satisfies the spark gap jitter requirements for ETA. The primary limitation of the trigger system is the rather narrow window of operating parameters which yield low-jitter. The limiting factor is the trigger amplitude which must be less than 160 kV to protect the trigger cable and connectors. Modification to extend the operating range by using cables and connectors capable of operating at higher trigger levels are in progress.

[1]A. Faltens, L. Reginato, R. Hester, A. Chesterman, E. Cook, T. Yokota and W. Dexter, High Repetition Rate Burst-Mode Spark Gap, UCRL #80934, June 15, 1978.

[2]G. Lauer, *Measurements of Distributions in Firing Time Delay of the ETA Test Spark Gap Switch*, ATA Note #64, March 21, 1979.

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Figure 1

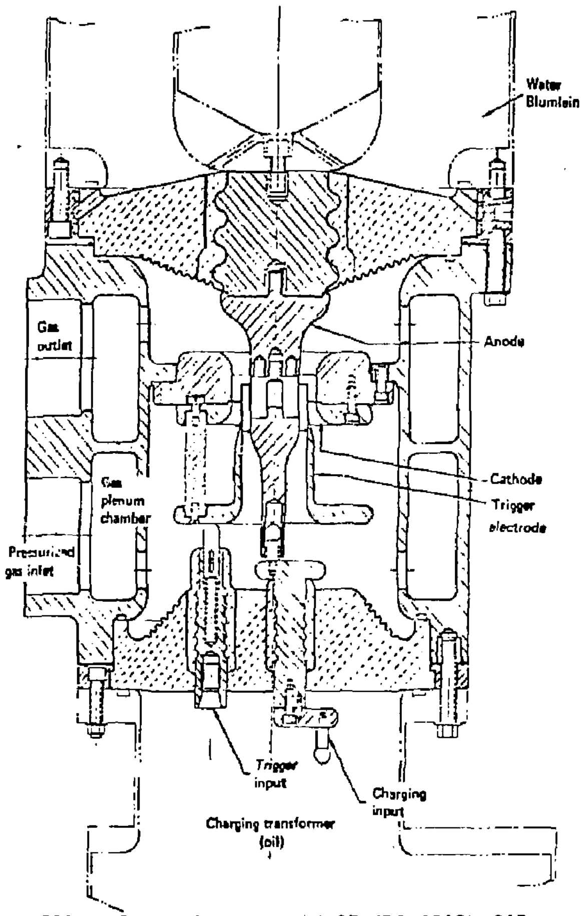

FIGURE 1. CROSS SECTION OF ETA SPARK GAP

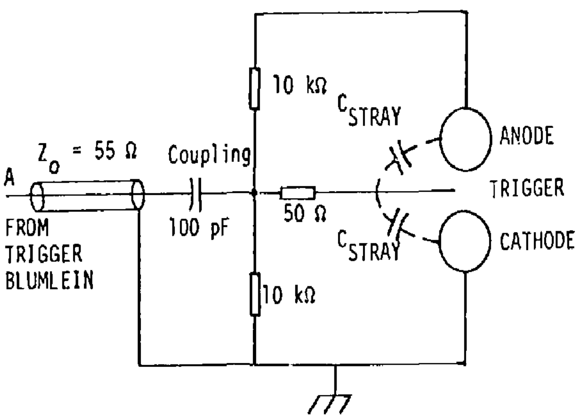

FIGURE 2. TRIGGER CIRCUIT FOR ETA SPARK GAP

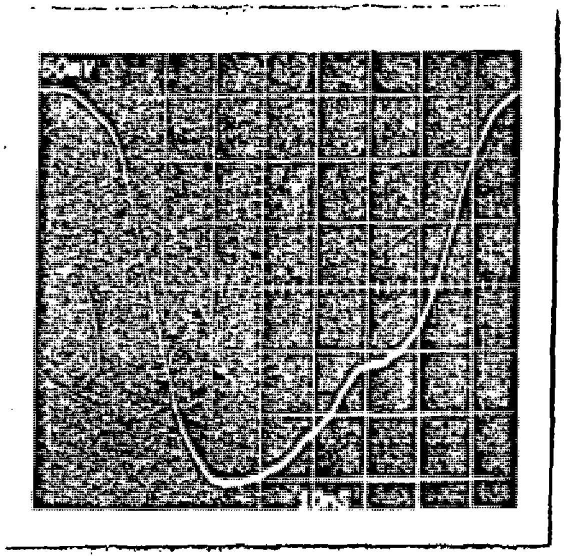

FIGURE 3A. TRIGGER BLUMLEIN OUTPUT

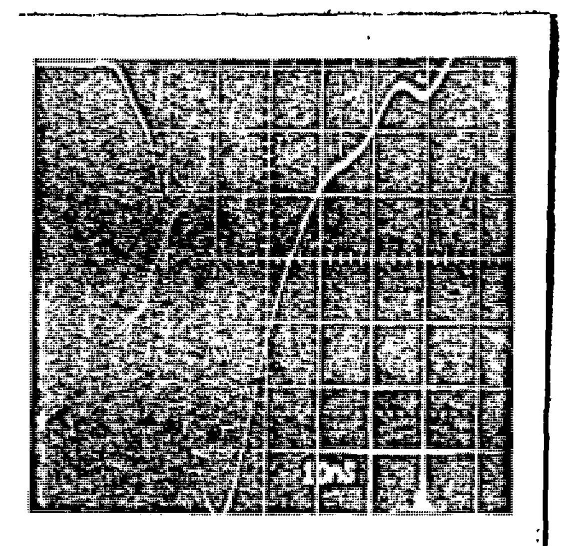

FIGURE 3B. TRIGGER VOLTAGE ON SPARK GAP SIDE OF COUPLING CAPACITOR

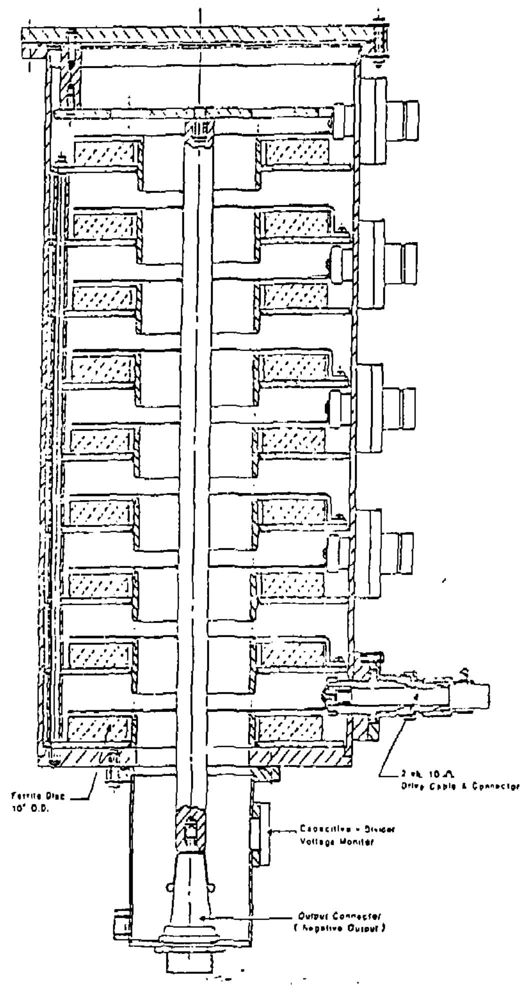

FIGURE 4. CROSS SECTION OF
SPARK GAP TRIGGER TRANSFORMER

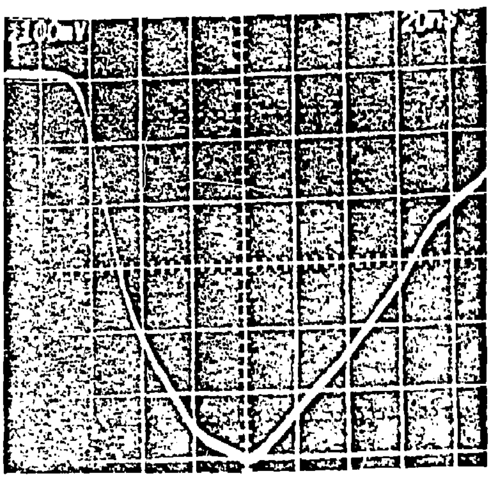

FIGURE 5. SPARK GAP TRIGGER TRANSFORMER OUTPUT (8 PULSES)

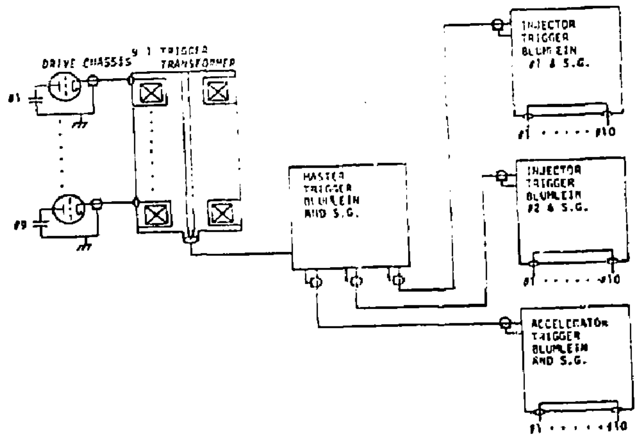

FIGURE 6. SIMPLIFIED BLOCK DIAGRAM - ETA SPARK GAP TRIGGER SYSTEM

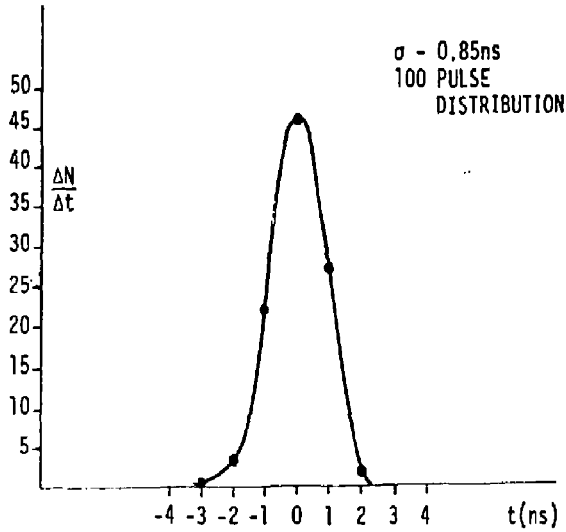

FIGURE 7. JITTER DATA DISTRIBUTION FOR INJECTOR TRIGGER BLUMLEIN S.G.

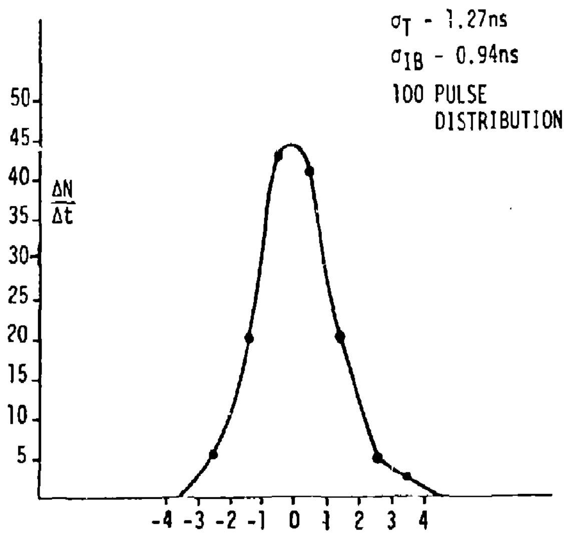

FIGURE 8. JITTER DATA DISTRIBUTION FOR INJECTOR BLUMLEIN S.G.

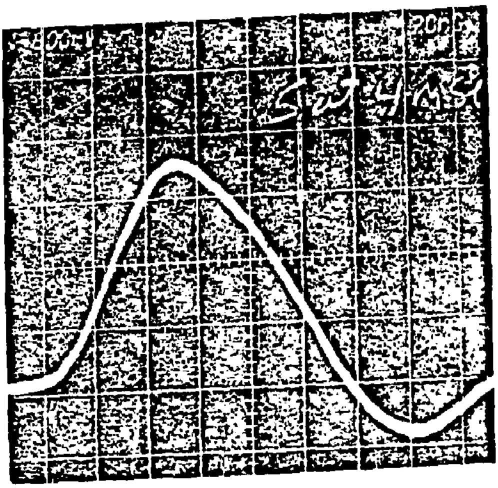

FIGURE 9. FIVE PULSE BURST OF SUMMED INJECTOR VOLTAGE

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