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THE FXR ONE-NANOSECOND-JITTER SWITCH

H. Bruce McFarlane
Ronald Kihara

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H. Bruce McFarlane and Ronald Kihara
Lawrence Livermore National Laboratory

Summary

A switching system using low-jitter spark gaps has been designed for a 20 MeV Flash X-Ray (FXR) linear induction accelerator that is being built at the Lawrence Livermore National Laboratory. The accelerator, which is now under construction, will consist of 54 modules connected in tandem. Each module will contribute up to 400 keV of energy to the electron beam traversing it.

The experimental work included a test of one accelerator module designed to produce 400 keV. Of particular concern was the thorough characterization of the Blumlein switch in terms of lifetime, voltage hold off and operating pressure range to produce minimal jitter and an acceptably low prefire rate.

We recorded the data by means of a computer-based data-acquisition system which was set up for later, automatic data reduction and display of the results. Optimization of the spark gap operating parameters resulted in a firing jitter of less than one nanosecond rms.

Introduction

Prototype tests of the FXR 20 Mev linear induction accelerator included a test of one accelerator module. The objectives of this test were to subject all the elements of the typical single accelerator module to numerous discharge cycles. We have recently completed 20,000 discharges using a coaxial midplane spark gap as the Blumlein switch. It is the purpose of this paper to report the results of these tests.

Experimental Setup

The one-module test stand is shown schematically in Figure 1.

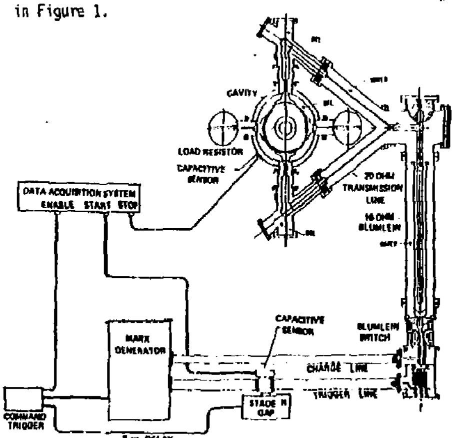

Fig. 1 - Block diagram of one-module test.

The Blumlein is charged by a 4-stage Marx generator. Each stage consists of an 80 nF capacitor. The four-stage, 20 nF Marx charges the 10-ohm, water-dielectric Blumlein through an inductor in about 2 microseconds. The Blumlein switch short circuits one end of the Blumlein near the peak of its charge. The trigger line is charged to the proper midplane voltage through a tap on the Marx generator.

The command trigger is split to send an ENABLE pulse to the data acquisition system (DAS), trigger the Marx generator, and also pass through a cable time delay to trigger the stage II gap near the peak of the Blumlein charge cycle.

The output from the stage II gap supplies the trigger to the main Blumlein switch and also sends a START pulse to the DAS. The Blumlein pulse energizes the accelerating cavity. At the cavity a capacitive voltage divider senses the signal and sends it as the STOP pulse to the DAS. The time between the STOP and START pulses is counted as the relative switching delay in the Blumlein switch. By analyzing a number of pulses, a measure of the time-jitter in the Blumlein switch is obtained.

The coaxial midplane spark gap switch is depicted in cross section in Figure 2. The coaxial geometry provides low inductance and hence a short pulse rise time. The midplane trigger electrode provides a large unbalance in electrode voltage and hence a short arc-formation time.

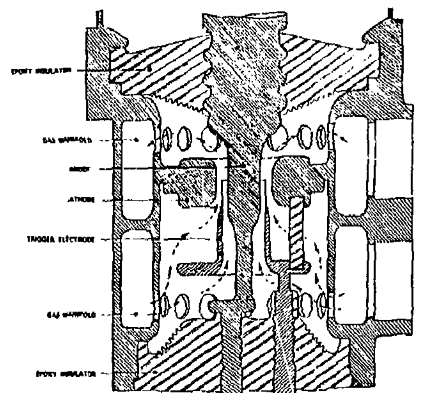

Fig. 2 - Cross section view of coaxial midplane spark-gap switch. The dashed line shows pattern of gas flow used to cool gap.

Jitter and Prefire Measurements

We constructed curves of the number of no-fires, prefires, and acceptable shots for selected values of voltage at different operating pressures. In both these tests and the jitter tests of the Blumlein switch, we charged the Blumlein to 290 kV by charging the Marx generator to 80 kV.

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At this voltage we ran several runs of 50 events each at pressures ranging from 320 kPa to 730 kPa absolute. No no-fires were recorded even at the highest pressures. As the pressure was lowered we experienced some prefires. Figure 3 is a graph of the pressure vs. number of prefires at 290 kV on the gap.

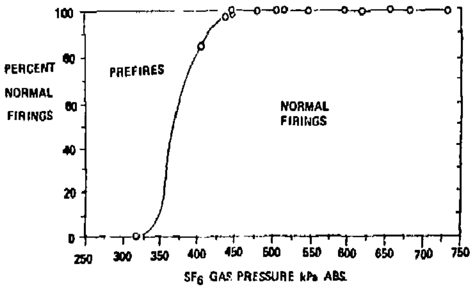

Fig. 3 - *Percentage of normal firings of main Blumlein gap vs. gas pressure. Each point resulted from 50 firings at that pressure. No no-fires were detected, even at highest operating pressure.*

The procedure we used was to set the desired pressure on various spark gaps (Marx, Stage II, Blumlein), then charge and discharge the system at intervals of 3 seconds. Suitable gas flows were maintained through the discharge devices to sweep out ionization products. In the case of the Blumlein switch a flow of 0.5 litres/second of SF_6 gas was used to cool the electrodes. Three signals are presented to the data acquisition system (Figure 4).

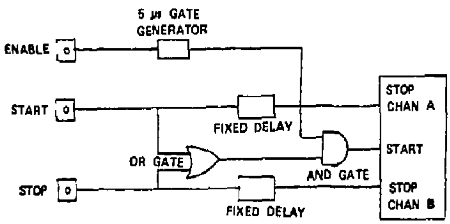

Fig. 4 - The data-acquisition system (DAS). By subtracting the count of channel A from that of channel B, we obtained the relative firing delay of the main Blumlein gap.

The first is an ENABLE signal without which no further data will be recorded. This signal comes from our command trigger. The reason for setting up the recording system this way is to preclude any data from Marx generator prefires. Occasionally the Marx prefired, and we felt that the data was then unreliable since the Stage II gap had not been triggered properly. The ENABLE signal starts a 5µs gate generator that drives one-input of a two-input AND gate.

The Stage II gap triggers the Blumlein gap. Part of this signal is also sent to the DAS as the START input. The STOP signal is derived from the cavity. As noted earlier, the time between START and STOP signals is a measure of the time the main Blumlein gap takes to fire. The clocks on the DAS are started by the START or STOP signals, whichever arrives at an OR gate first. The clock on channel A is stopped by a delayed START signal while channel B is stopped by the STOP signal, also delayed.

The information from each clock is recorded in a disc file with an event number. A series of events are recorded into the file with a unique name for later correlation with experimental conditions noted in the log. The DATE, TIME, DEVICE UNDER TEST, PRESSURE, and VOLTAGE are recorded in the file.

Later the recorded information is processed to produce a printed record showing each event and the delay time. If channel A shows a large number (overflow) and channel B is small, a prefire is presumed. If channel B registers an overflow it is indicative of a no-fire. The printout shows the maximum and minimum delay times recorded, and values for the MEAN and RMS DEVIATION (σ) are printed. This latter term is defined as follows:

$$\sigma = \sqrt{\frac{(\bar{X} - Xi)^2}{n}}$$

where σ is the rms deviation
$\bar{X}$ is the sample mean
Xi is the sample value
n is the number of samples

Data from the disc files is analyzed. The difference between the maximum and minimum delay times is divided into time slots of equal length. The number of events having delay times in each slot are counted. The results are then plotted on a bar graph such as Figure 5. The bar graph is an easy way to see if there are any gross statistical aberrations in the data.

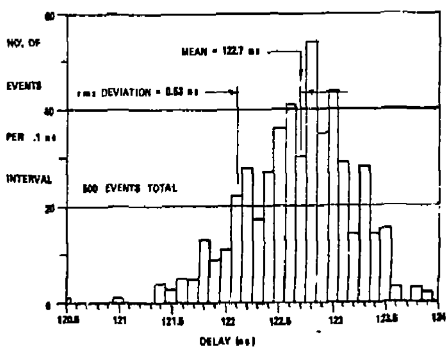

Fig. 5 Delay histogram of typical one-module test run of 500 events. Main-Blumlein-gap pressure (SF_6): 755 kPa abs., gap voltage: 290 kV.

We ran more than 20,000 discharges to life test the Blumlein switch. Each group of 500 or 1000 discharges was analyzed to see if any of the gap statistics were changing. We made a plot of each file similar to the above and also printed out the data. Our data shows conclusively that the rms deviation from the mean (jitter) did not exceed 1 ns. Every discharge was monitored and recorded. The example shows a jitter of 0.58 ns.

During the running of the one-module test, we found a number of design features that could be improved. We made these changes prior to construction of the four-module test stand. One of these changes was to replace the hollow tantalum anode of the Blumlein gap with a solid anode made of Corrosion Resisting Steel (CRES).

We also used a more reliable and faster-rising trigger pulse from our Stage II gap on the four-module test than we used on the one-module test. It may be for this reason that the delay statistics recorded from the first of the four-modules show a jitter of even less than for the one-module test. In the example of Figure 6 the jitter is only 0.35 ns.

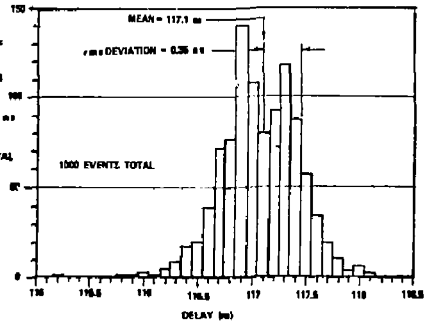

Fig. 6 - Delay histogram of typical four-module test run of 1000 events. Gap voltage: 300 kV, gap pressure: 445 kPa abs.

Another change made prior to the four-module tests was the reorientation of the cavity to a symmetrical lateral feed rather than from the top and bottom. This change eliminated the right-angle bend and also shortened the water transmission line. The new configuration is shown in Figure 7.

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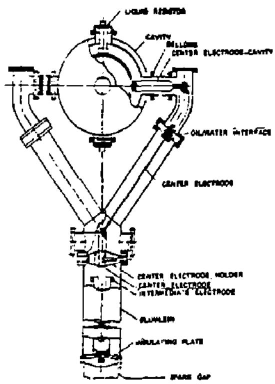

Fig. 7 Schematic drawing of Blumlein and cavity used on four-module test stand.

The shape of the output pulse obtained from the four-module test (Figure 8) is better than the pulse from the single-module test. The top of the pulse is relatively flat, the rise time is about 30 ns (10% - 90%) and the width about 80 ns (FWHM).

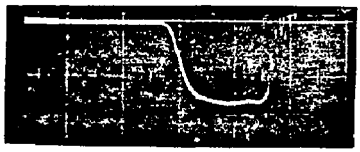

Fig. 8 Cavity voltage on four-module test. Horizontal: 50 ns/div., vertical: 250 kV/div.

Conclusion

The electron beam of the FXR linear induction accelerator travels at near-relativistic velocity through a series of 54-pulse modules. Each pulse must coincide with the arrival time of the beam. This requires timing accuracy of 1 nanosecond or less. We have tested a coaxial midplane spark gap switch and have shown it to have a statistical time jitter over a large number of pulses of 0.35 ns rms. The use of an automatic data recording and reduction system allowed us to measure each pulse that was fired and to reduce the data to statistical bar graphs.