Multi-Pulse Diode-Isolated-Blumlein Induction-Cell Drivers

Los Alamos National Laboratory
Los Alamos, NM, USA

Abstract

The Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility at Los Alamos National Laboratory (LANL) uses two, linear-induction accelerators (LIAs) for flash, x-ray radiography of hydrodynamic tests. The Axis-I LIA uses a single, beam pulse of 60 ns, 20 MeV, and 2 kA. The Axis-II LIA uses a long beam pulse, and a kicker to generate four radiation pulses.

The National Nuclear Security Agency (NNSA) is planning a new, multi-pulse, single-axis, electron LIA for hydrodynamic experiments. One method for generating multiple beam pulses on a single axis, without a kicker, is to multi-pulse the injector and each accelerator cell. Diode-isolated Blumleins are being considered as the pulsed-power drivers for the accelerator cells.

On DARHT Axis-I, the Blumleins are dc connected to the cells such that when they are charged, the connected cells’ magnetic cores are also preset. With diodes in the circuit, this dc path is not available. This paper describes the 300-kV, diode-isolated Blumlein concept, performance requirements, Blumlein charging options, core preset methods, and circuit simulation results.

I. INTRODUCTION

The DARHT Axis-II linear induction accelerator (LIA) can produce four beam-current and X-ray radiographic pulses. This ability to produce multiple pulses on a single axis is advantageous for many reasons. Working in conjunction with the single pulse from Axis-I, the DARHT facility can produce quasi-3D images of hydrodynamic objects.

Axis-II generates its radiographic pulses by extracting kicked beam-current pulses from a longer 1.6-µs-long current pulse. This architecture was chosen for many reasons considering the type of cathode involved (thermionic), pulsed power systems (Marx pulse-forming networks PFNs), accelerator cells, amount of magnetic material (Metglas) and kicker technology [1, 2, 3].

In new machines, the desire is to move away from long-pulse injectors from which multiple pulses are extracted, to a paradigm in which the injector can produce multiple short pulses which are then transported in the accelerator to the X-ray conversion target [4, 5]. Various topologies of injector, cathode, accelerator and pulsed power topologies are being considered for the Scorpions Radiographic accelerator [5]. Since the accelerator cells need to be driven by pulsed-power sources capable of multiple pulses, one of the leading topologies is to use high-voltage solid-state diodes to electrically isolate multiple Blumleins. Other types of pulsed-power sources include series-connected pulse-forming lines (PFLs) and combinations of the two [5, 6].

II. CONCEPTS

In this section, we describe the diode-isolated Blumlein concept, introduce the important specifications of the 300-kV solid-state diodes, and review the Blumlein charging and core preset methods that are necessary when diodes are inserted into the circuit.

A. Diode-Isolated Blumleins

Figure 1 shows a simplified diagram of two example Blumleins connected by high-voltage solid-state diodes to two induction cells. There could be any number of Blumleins each being isolated by diodes. In this figure, Blumlein I is first triggered generating a high-voltage output pulse (negative polarity) which turns on diode D1 (green) allowing the voltage to be applied to the induction cells. We note that there are two cells shown, but a single cell or multiple cells can be connected, again with an appropriate number of diode assemblies. With the application of a negative potential to the induction cells, and with the second Blumlein output being at zero potential, diodes D2 (red) are reverse biased and turned off isolating the second, or other Blumleins from the first pulse. The arrows show the direction of pulsed current flow. At some time after the first pulse has recovered, the next Blumlein is triggered generating a second pulse. In
like manner, the diodes D1 are reverse biased and turned off isolating the first Blumlein from the output pulse of the second. The first and second pulses from the two Blumleins are shown graphically at the bottom of the figure. An arbitrary time delay may be inserted between the two pulses contingent upon output pulse width and diode recovery times. The two independent pulses, in this example, appear as multiple pulses on the same load shown graphically at the bottom of the figure.

B. Solid-State Diode

The primary solid-state diode specifications are listed in Table 1. We have tested and evaluated diode assemblies from three vendors. Generally, each diode assembly is comprised of multiple layers of small 10-kV diodes in parallel to obtain the high-current capability and voltage standoff. Additionally, each layer or stage has additional capacitance for capacitive voltage grading. These assemblies are similar to other diode assemblies [7, 8].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocking Voltage, ( V_B )</td>
<td>300</td>
<td>kV</td>
</tr>
<tr>
<td>Forward current, ( I_F )</td>
<td>5</td>
<td>kA</td>
</tr>
<tr>
<td>Forward voltage drop at ( I_F )</td>
<td>5</td>
<td>kV</td>
</tr>
<tr>
<td>Max recovery time, ( t_{rr} )</td>
<td>100</td>
<td>ns</td>
</tr>
<tr>
<td>Max end-to-end capacitance, ( C_T )</td>
<td>100</td>
<td>pF</td>
</tr>
</tbody>
</table>

Table 1. Solid-State Diode specifications.

An end-to-end capacitance specification is included to limit the conducted capacitive displacement current, \( i(t) = C \frac{dv}{dt} \), through the diode assembly during the rise and fall times of the blocking voltage pulses. Using vendor-supplied diodes, we have been able to generate two diode-isolated pulses both on a resistive test load and on a test induction cell. The induction cell has enough Metglas, assuming full preset, to accommodate two, 110-ns-wide 250-kV pulses before saturating [9, 10].

Figure 2 shows a SPICE-simulated output of four pulses drive by diode-isolated Blumleins. The diodes were simulated using the specifications of Table 1. The time spacing between pulses is shown in the figure, and the total pulse spacing from first to last pulse is 3000 ns.

C. Charging and Core Preset Options

The simplified circuit in Figure 3 shows a typical Blumlein used on Axis-I connected to an induction cell (solid line). The Blumlein includes the center conductor/tube, the intermediate conductor/tube and the outside ground cylinder. In the Axis-I configuration, the cells (two per Blumlein) are dc connected to the center conductor. When each Blumlein is charged with a 4.5-μs sinusoidal waveform approximating a 1-cosine function, part of the current flows through \( C_2 \) to ground, and the other portion flows through \( C_1 \) to the center conductor, and along the transmission lines to their respective accelerator cells. The current flowing through \( C_1 \) presets the cores to their positive remanent point on their respective B-H curves. The arrows (orange) indicate the direction of the charging and core preset currents.

In Figure 3, the dashed lines represent the circuit configuration for the diode-isolated Blumlein concept. Adding diodes in this manner is problematic for at least two reasons. One is that \( C_1 \) can’t be charged because the diode blocks current flow, and the second is that the ability to preset the induction cell cores during Blumlein
charging is lost. Note that C2 can be charged, and that C1 will charge to the extent that output cable capacitance allows.

Several options are being studied to remedy these shortcomings. One is to add a series resistor-inductor network (shown in Figure 3) from the center conductor to ground on the Blumleins. This is a similar concept to that which is implemented on the Axis-I prime power tank. The inductor-resistor combination, if chosen properly, allows a quasi-dc charge path to ground and a high impedance load during the main pulse. Another option is to add a bypass inductor around the diode assemblies. This option allows for a dc charge current that will both allow charging of the Blumleins and presetting of the induction cell cores. The downside, of course, is that current will flow in the inductor when the diode is in reverse blocking mode. The effect of this current is being studied. A third option is to preset the induction cell cores by an external dc power supply either with an isolation inductor or single-pole high-voltage switch.

III. SUMMARY

We have illustrated the diode-isolated Blumlein concept and explained its operation. The primary specifications for the diodes have been introduced and a SPICE circuit output showing four pulses has been included. When the diodes, which must be placed near the induction cells, are added, the Blumleins, in their present configuration, are unable to be charged and the induction cell cores are unable to be preset to their remanent point in their respective B-H curves.

Solutions to these shortcomings include additional dc paths to ground such as the resistor-inductor circuit connected to the Blumlein center conductors, diode bypass inductors, or additional circuitry dedicated solely to presetting the cores connected by means of isolation inductors or high-voltage switches.

We are continuing development of the diode assemblies, testing of their performance with multiple isolated Blumleins in both resistive loads and induction cells, and are examining the tradeoffs between the options posed above to allow core preset and Blumlein charging.

IV. REFERENCES