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MODERNIZATION OF THE MARX AND RIMFIRE TRIGGERING SYSTEMS FOR THE HERMES-III ACCELERATOR *

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Abstract

Abstract— HERMES III is a 20-MeV linear induction accelerator that was constructed at Sandia National Laboratories in the late 1980's and continues operation to this day. The accelerator utilizes 10 Marx banks for its initial energy storage and pulse formation. These Marx banks discharge their energy into 20 intermediate storage capacitors which, in turn, feed 80 pulse forming lines that further condition the pulse. Transmission line feeds from the pulse forming lines then deliver the electrical energy to 20 induction cavities arrayed along the axis of the machine to build the final output pulse along a central magnetically insulated transmission line (MITL). There are two triggering systems within the accelerator that work together in this energy discharge process. One simultaneously triggers the initial discharge of energy from each of the 10 Marx banks; the other staggers the triggering of the Rimfire gas switches following each intermediate storage capacitor so as to properly synchronize the energy delivery to the downstream cavities and the MITL with the pulse propagation along the MITL. Until recently, these triggering systems were the original systems dating back to the initial commissioning of the accelerator, however both have now been replaced with new and more modernized systems. Design details for both triggering systems will be presented, along with an overview of some of the initial operational data from the HERMES III accelerator using these new triggering systems.

I. INTRODUCTION

The HERMES III accelerator (Fig. 1) is a unique 20-MeV gamma ray simulator that was first commissioned at Sandia National Laboratories in 1988 [1]—[3]. Today it still finds widespread use as both a means to produce extreme radiation environments for effects testing, as well as a test bed for internal diode, diagnostic, and other research and development efforts. The accelerator is still operating with many of its original systems, many of which have components that are no longer manufactured and for which it is difficult to find replacements. As a result, efforts to change out these systems with ones that are more modern and are easier to maintain have recently begun. The triggering systems for both the Marx banks and intermediate store gas switches are two such systems that have been replaced within the past 12 months.

Figure 1. The Marx oil tanks (left, right) and induction cavities (center) of the HERMES III accelerator.

The basic layout of the pulsed power systems and components making up the accelerator is illustrated by the diagram shown in Fig. 2. HERMES III uses ten Marx banks, five along each side of the accelerator, for its initial energy store. Each Marx bank has 24-stages consisting of 100-kV 1.3-μF capacitors, and when fully charged they have a stored energy of 156 kJ. The first triggering system on the accelerator is thus an electrical triggering system that simultaneously initiates the discharge of all ten Marx banks to begin the power flow and pulse compression/pulse shaping processes.

Once triggered, the Marx banks discharge their stored energy into two water-dielectric intermediate store (IS) capacitors, both of which have capacitances of 19 nF. These IS capacitors are allowed to charge until Rimfire gas switches downline of each capacitor are triggered by a second triggering system which is a laser system. The triggering of the Rimfire switches is not simultaneous but staggered from the south to the north end of the machine to match the transit time of the power flow along the central magnetically insulated transmission line (MITL). As each Rimfire switch is triggered, then, energy from the IS capacitors is transferred into 4 parallel 1.1-MV water-

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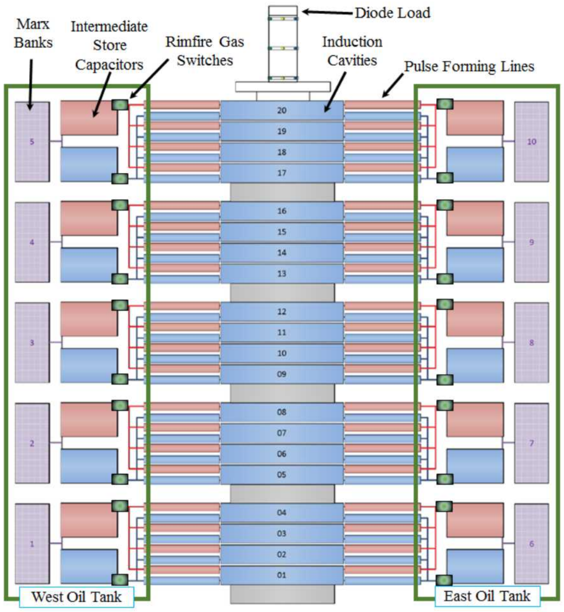

Figure 2. Diagram of the HERMES III pulsed power architecture.

dielectric pulse forming lines (PFLs) to further shape the power flow.

Self-break water switches transfer the energy from the PFLs to regular water-dielectric transmission lines (TLs), which have a second self-break water switch to sharpen the rise time of the power pulse. Four TLs, two from each side of the machine, then feed each of the twenty 1-MV induction cavities. These cavities allow the current pulses from the four feed TLs to be added within each cavity, and then the 1.0 MV from each summed cavity pulse is added along the central MITL to establish approximately 20 MV at the output of the accelerator [4].

Beyond the 20th cavity, an extension to the MITL typically delivers the output from the machine to an electron diode and Bremsstrahlung converter assembly, though occasional experiments using other diode configurations have been performed. When operating at typical charge and timing parameters, the accelerator delivers a pulse to the diode having voltages of 18-20 MV, currents of 600-700 kA and a full-width, half-maximum (FWHM) of 40-50 ns.

This paper describes the designs of the new Marx and Rimfire triggering systems that have been installed on the HERMES III accelerator within the past year. The next section of this paper provides a description of each of these systems, and then Section III provides a review of their performance and the performance of HERMES III after they were installed. Section V then closes with summary statements and other final remarks.

II. DESCRIPTION OF NEW TRIGGERING SYSTEMS

As described above, there are four stages of switches on the HERMES III accelerator: the last two stages are self-break switches and primarily affect pulse shape, while the first two, the Marx and Rimfire switches, are command triggered and are key for defining the power flow. Because there is a finite transit time for the power flow along the length of the MITL (from bottom to top in Fig. 2), the Rimfire switches, unlike the Marx switches, must be staggered by 8.67 ns in their triggering along the length of the machine; that is, each set of four Rimfire switches must be delayed by this amount relative to the preceding set to allow time for the power pulse to propagate along the length of the MITL adder. Thus, the Rimfire switches also perform the initial pulse shaping for the accelerator.

A. Marx Electrical Triggering System

In order to ensure that the voltages on the intermediate storage capacitors are within a few percent of each other when the Rimfire switches are triggered, it is desirable for the trigger jitter between all ten Marxes not be more than a few 10's of ns. For these timing requirements, an electrical triggering system is adequate. The previous Marx trigger system consisted of a two-stage pulser that in turn triggered two parallel Marx trigger generators, or MTGs, one located in each oil tank. The new electrical triggering system produces a fast rise-time, high-voltage trigger pulse in a similar manner, from a two-stage system that in turn is used to trigger two redesigned MTGs.

The primary stage is a compact Marx generator (model MG15-3C-940PF), developed by Applied Physical Electronics, L.C. (Fig. 3, top) [5],[6] and which is comprised of 15 stages itself. When charged to 40 kV, the APELC Marx is capable of providing electrical pulses of up to 300 kV, with a rise time of 3 ns and a FWHM of 25 ns. For the purpose of triggering the HERMES III MTGs it is necessary to operate it at only half of that voltage (*i.e.*, with a 150-kV output). The Marx is triggered with a lower-voltage (18 kV), rack-mounted thyratron-based pulser (APELC model HRR-TU-18kV), which in turn is triggered with an optical signal delivered to it from the HERMES III control and data acquisition systems.


Figure 3. The APELC Marx bank (top) [6], the oil-filled cable junction enclosure (lower left), and the new MTG in the west oil tank (lower right).

The APELC Marx vessel has provision for only one output cable (type DS-2042), so in order to be able to trigger two MTGs, a high voltage junction enclosure was designed (Fig. 3, lower left). The enclosure is made from a 20-in.-long, 10-in.-diameter MDC stainless steel full nipple having 13.25-in. flanges on each end. For electrical insulation a high-density polyethylene (HDPE) sleeve with a 1.25-in. wall thickness is slid into the MDC tube, and a 2.0-in.-thick disk of HDPE lines the bottom. The remaining volume is filled with transformer oil to further insulate the cable bus, which is a 6.25-in.-diameter, 0.75-in.-thick brass disk to which the center conductors of the three cables are connected. DS-2121 cables are run from the junction enclosure to the MTGs in the east and west oil tanks, and fittings on the top flange allow the ground braids of these cables and the cable from the Marx to be connected to the enclosure. Small D-dot probes in the connectors for the DS-2042 at the Marx and at the junction enclosure allow the pulse generated by the Marx to be monitored as it propagates to the MTGs.

The new MTGs are also small Marx banks (Fig. 3, lower right). Each MTG is comprised of ten 80-nF capacitors, and the capacitors are charged to +/- 60 kV. The MTGs then deliver a ~600 kV trigger pulse to each of the ten HERMES III Marxes via a solid copper pipe bus in the east and west oil tanks.

B. Rimfire Switch Laser Triggering System

Prompt, low-jitter closure of the Rimfire gas switches that provide power to the cavities along the length of the HERMES III adder MITL is a key requirement for producing an output pulse with a fast rise-time and for maximizing its amplitude. Equally important is low jitter and accurate sequencing of the trigger pulses delivered to the sets of Rimfire switches. Due to the tighter timing requirements for the Rimfire switches relative to the Marx generators, a laser triggering system (LTS) is necessary for initiating these switches. The design motivation and methodology for this new system has been described in detail elsewhere [7],[8], and therefore the system will only be briefly discussed here for context.

The previous Rimfire LTS used a single KrF laser that was split into 20 beamlets along paths whose paths lengths were set to define the trigger timing for each Rimfire switch [2],[9]. The new system uses ten solid-state Tempest 300 Nd:YAG lasers placed in RF cabinets adjacent to each upper and lower pair of Rimfire switches (Fig. 4). The lasers operate at a fundamental wavelength of 1064-nm but have internal 2nd and 4th harmonic generators to shorten the wavelength to 266 nm [10].

As there are 20 Rimfire switches in HERMES III, each laser is responsible for triggering two switches. Figure 5 illustrates the layout of components on the optical breadboards for each Tempest laser system. The laser head is placed near one of the corners of the breadboard away from the switch ports, and a 3X beam expander is mounted onto the laser head at the beam output. The expander increases the diameter of the beam from the 6-mm emitted by the Nd:YAG crystal to 18 mm, and by making slight adjustments to the lens separation within the expander it can also correct for the small amount of beam divergence at the laser output. This adjustment can also be used as a convenient means of varying the location of the focal spot in the triggered gaps of the Rimfire switches, in addition to physically moving the focal lenses toward or away from the Rimfire switches.

Following the beam expander is a beam splitter that divides the laser output into two beamlets, thereby accommodating the triggering of both the upper and lower

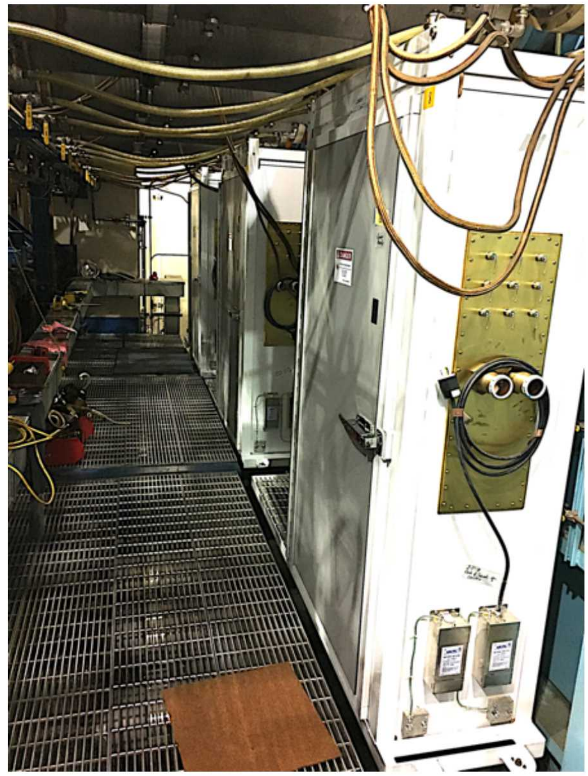

Figure 4. Three of the laser RF enclosures are shown along the east HERMES III oil tank.

switches. From the beam splitter, the beamlets follow paths of equal length, reflecting off 3 turning mirrors before being directed into the focusing lens – each of which have a focal length of ~1.25 m – and the fused silica viewport for each switch's SF_6 volume.

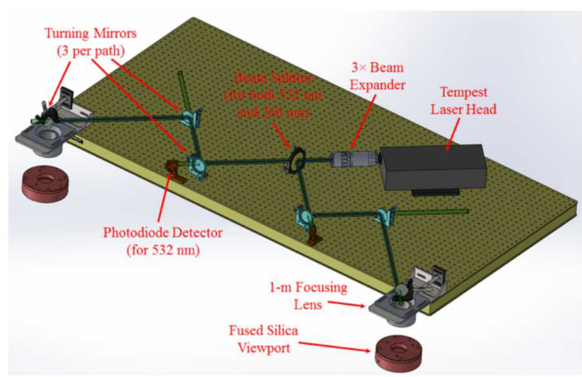

Figure 5. Optical path and components within each laser RF cabinet.

III. PERFORMANCE DATA

The new triggering systems have demonstrated performance similar to or better than the legacy systems that they have replaced, thereby maintaining/preserving the previous performance of HERMES III. Closure times of the triggered switches and pulse arrival times in the PFLs and TLs, which are dependent upon closure times of the self-break PFL and pulse sharpening switches are compared in Table 1. Columns 1–4 show the average

Table 1. Average HERMES III switch spread times and machine delays for the legacy triggering and new systems (12 shots each). Standard deviations for each are shown in blue.

	Avg Marx Switch Spread, Std Dev (ns)	Avg Rimfire Spread, Std Dev (ns)	Avg PFL Switch Spread, Std Dev (ns)	Avg TL Switch Spread, Std Dev (ns)	Avg Marx Trig to γ Delay, Std Dev (ns)
Legacy Trig Systems	49.9	16.5	42.4	39.1	2185.5
	8.7	5.0	12.5	7.5	25.4
New Trig Systems	32.9	7.7	70.1	39.3	2195.7
	7.9	3.2	16.8	15.4	12.2

switch spread times (i.e., time difference between latest and earliest switches) for 12 arbitrarily-selected shots. Column 5 shows the total machine delay for these shots; that is, the time between the APELC Marx output and the arrival of γ radiation at a Compton diode in the test cell. While the shots were "arbitrarily selected", only shots for which machine operation was nominally "good" (*i.e.*, shots with no switch pre-fires or diagnostic anomalies) are considered here in order to facilitate a fair comparison.

Two MITL anode current waveforms from each group are time-aligned and overlaid in Fig. 6. As can be seen, overall features are nearly the same, again demonstrating that machine performance is preserved. The new triggering systems appear to be enabling better timing control of Marx and Rimfire triggering. The self-break switches are unchanged, however, and at least for the shots considered here displayed more jitter during the recent tests. The net result is a relatively-unchanged machine delay.

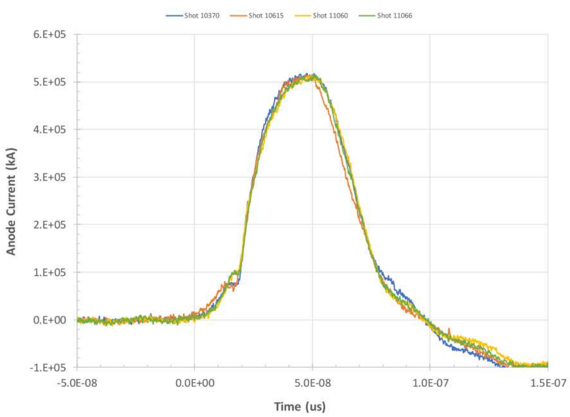

Figure 6. Overlay of two anode current waveforms from shots before the triggering system upgrades and two after.

IV. SUMMARY AND CONCLUDING REMARKS

At a minimum the new Marx and Rimfire switch triggering systems have been shown to preserve the baseline performance of HERMES III, an absolute requirement for any system change/upgrade. These more modern systems will also greatly simplify maintenance, as replacement parts for each are readily available. Some immediate improvements are seen in accelerator performance, as well, as the placement of independent lasers at each upper/lower Rimfire switch pair is enabling more precise timing for switch triggering. The possibility of pulse shaping is also realized, should there be a need during any future research efforts that may be conducted with HERMES III. While the improvements to the Marx and Rimfire triggering are apparent, it is also clear that some improvements to the ensemble of self-break switches are now needed in order to be able to fully realize the benefits that the new command triggering systems bring to the overall performance of HERMES III.

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