Sandia National Laboratories

SOLID STATE LASER TRIGGERING SYSTEM FOR THE HERMES-III ACCELERATOR

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Abstract

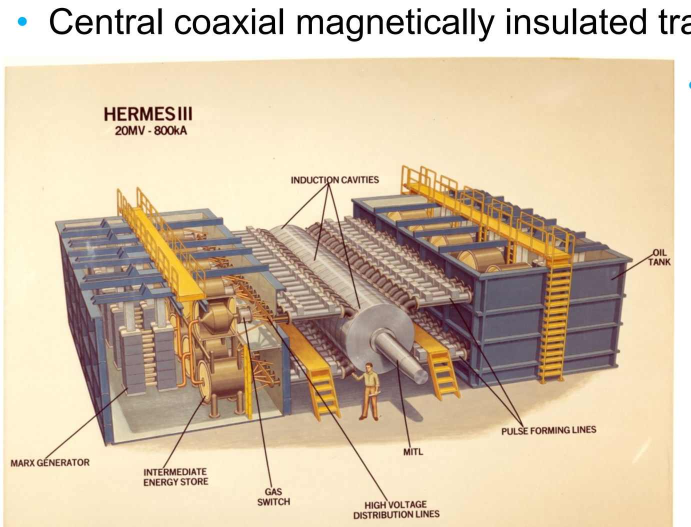
The Hermes III accelerator is a 20-MV linear induction accelerator that has been in operation at Sandia National Laboratories since the late 1980's. Energy is initially stored in the accelerator in ten Marx banks that are discharged into twenty intermediate store capacitors. These intermediate store capacitors are then switched with SF_6-insulated high voltage Rimfire switches into eighty parallel pulse forming lines that further condition the pulse before finally delivering it to the twenty induction cavities arrayed along the axis of the machine.

Currently, a single 0.9-J KrF laser operating at 248 nm, the output of which is divided into twenty separate beamlets, is being used to trigger the Rimfire switches. However, as part of a modernization plan for the accelerator, the gas laser system is being replaced with a new solid-state laser triggering system. The new system is comprised of 10 flash-lamp pumped, Q-switched Nd:YAG lasers (Tempest 300), each having an energy output of 35~40 mJ at a wavelength of 266 nm. Each laser will be responsible for triggering two Rimfire switches.

Overall reliability for the accelerator's operation with these new lasers is expected to increase, and by varying the times at which the individual lasers fire it becomes possible to tailor the shape of the output pulse. The optical layout and other details of this solid-state laser triggering system are presented, along with initial operational data from the HERMES III accelerator using this system.

Overview of the HERMES III Accelerator

- Ten 24-stage Marx banks, with 2.4 MV, 156 kJ peak voltage and energy
- 20 intermediate energy store capacitors ($C_{I\text{-store}}$ = 19-nF) with water dielectric
- 20 laser-triggered Rimfire gas switches, 2.2-MV rating
- 80 1.1-MV pulse forming transmission lines (PFLs)
- 20 1-MV induction cavities
- Central coaxial magnetically insulated transmission line (MITL)



Artist's rendering of the HERMES III accelerator

- Prompt closure of the Rimfire gas switches is key to defining the shape of the pulse delivered to the load
  - → Optimum pulse shape depends upon
    - Low-jitter triggering of each gas switch
    - Low pre-fire rate for each switch
- Triggering time for a given switch depends upon the location of the switch's placement in the accelerator
  - Four gas switches associated with each pair of opposing Marx generators are triggered simultaneously
  - Adjacent groups of 4 switches are successively delayed by 8.66 ns (proceeding from the low voltage end of the accelerator up to the high voltage end) to account for pulse propagation time along the MITL adder

Laser Triggering for Rimfire Switches

Legacy KrF System

- The present HERMES III laser trigger system uses a single KrF discharge-pumped laser to provide 0.9 J of radiation at 248 nm over a 30-ns pulse[4]
- Beam transport tubes, optical towers, and optical cabinets keep the beam enclosed along entire path to the switches
- Total path length (laser to switches) is approximately 32 m

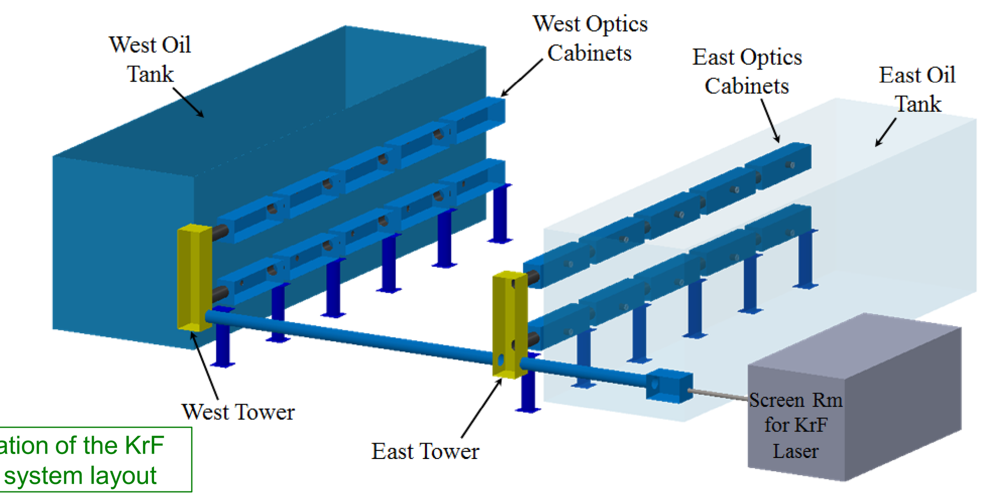


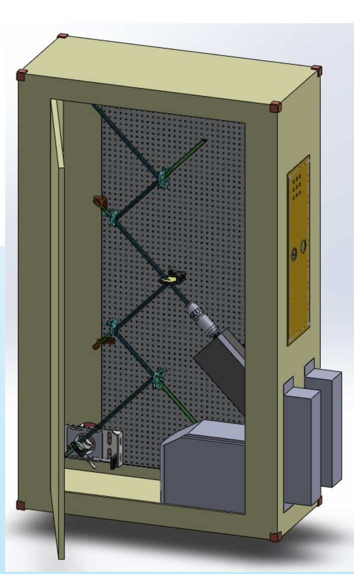
Illustration of the KrF laser system layout

New Solid State System

- The KrF laser system has the convenience of maintenance and operation of only a single laser system
- But the system has several drawbacks:
  - Because of its age, the system is becoming less reliable, and finding replacement parts for it is very difficult as the system is no longer manufactured
  - Failure of the KrF will cause a shot to fail and/or hold up operations
  - The fluorine used in the system has undesirable health risks associated with it

Tempest 300 laser head, power supply and hand-held controller

- A new system using 10 solid-state *Tempest 300* Nd:YAG lasers has been designed and is currently being assembled
- Uses commercially available lasers
- Lasers have 1064-nm fundamental; internal 2nd and 4th harmonic generators shorten the fundamental to 266 nm
- Each laser in this system will be responsible for triggering two Rimfire switches
- Concerns with hazardous Fluorine gas are now eliminated!



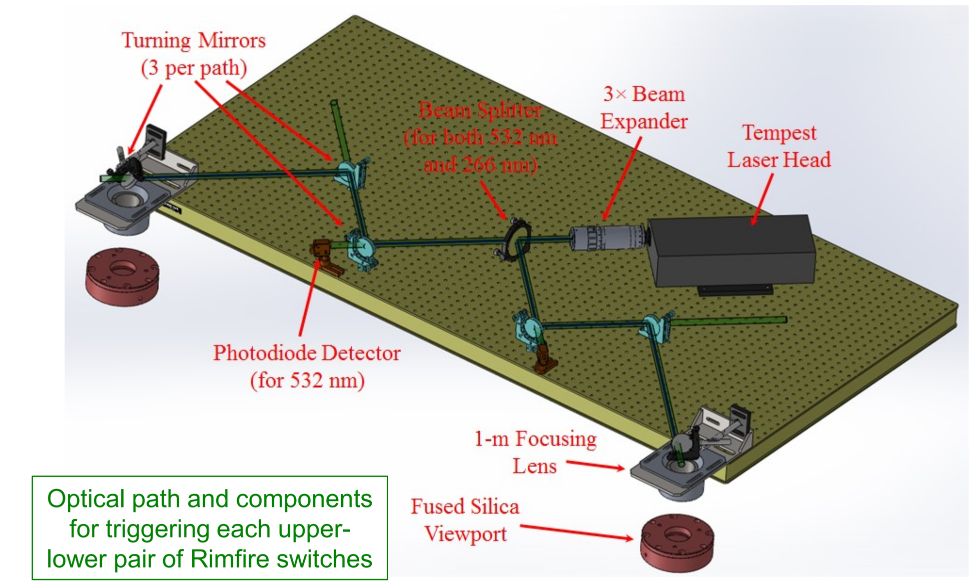
← Illustration of RF-tight enclosure for the Tempest lasers

Photo of the cabinets → after lasers and optics have been installed

- Each laser is mounted on its own optical breadboard inside an RF-tight enclosure, as shown below
- Enclosures to be positioned adjacent to two of the Rimfire switch ports – an upper port and a lower port – to provide triggering for these switches
- Frames were constructed for the cabinets that straddle the existing pedestals

Optical System

- In the present system, each KrF beamlet requires from 10 to 14 optical components for direction to its target switch
- Placement of lasers just outside the oil tank ports for the new system will allow the number of optical components to be considerably reduced
- Not including lenses for beam expansion, the new system requires only 6 optical components for each pair of Rimfire switches



Optical path and components for triggering each upper-lower pair of Rimfire switches

Key Parameters for Laser Triggering

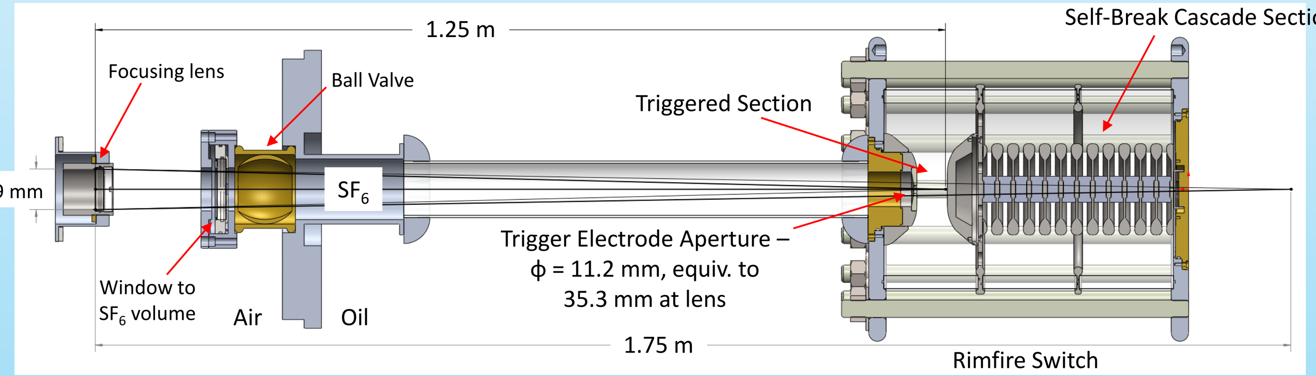
- Laser energy
  - Minimum laser energy for reliable triggering of the HERMES III Rimfire-style switches has varied depending upon design details[4,6-8]
  - Hamil, et. al.[4], indicate that with the KrF system the minimum laser energy delivered to any one Rimfire switch was 15 mJ, while maximum was 25 mJ
- Focal length of lens
  - Having a longer focal length lens enables creation of longer arc channels[9]
- Beam f/# (= ratio of focal length to beam diameter)
  - Larger f/# works with longer focal length lens to create a longer arc channel
  - Smaller f/# allows creation of a higher field in a more localized spot

Energy Budgeting and Measurement

- If each laser provides 40 ~ 45 mJ at 266 nm, the energy delivered to each switch is expected to be 14.0 ~ 15.7 mJ
- After optimization, the measured laser output in each cabinet has thus far been 41.0 ± 2.8 mJ
- Due to unequal energy splitting, measured energy after focusing optics is 11.8 ± 1.2 mJ for the upper paths and 18.9 ± 4.5 mJ for the lower paths
  - If the upper and lower path energies are averaged, measurements then agree well with the initial estimates

Lens Focal Length

- The KrF system on HERMES currently uses an overly-long focal length lens to focus the beam in the triggered gap
  - Lens focal length is 1.75 m vs. the actual distance of 1.25 m to the triggered gap
  - The beam then creates a spark on the electrode surface and material is ablated to close the switch
  - While this can work, switch closure times are likely slower than if the gas between the electrodes is broken down[11]



Beam f/#

- Hot spot creation due to beam f/# should be balanced with long arc channel created by long focal length
  - → Want to create long arc channel to close the triggered gap and yet concentrate the beam energy sufficiently rapidly to ensure that the spark is energetic
- Observations of other laser triggered switches suggest that a 10-mJ laser with an f/# of 40 or less should reliably trigger an SF_6 switch[12]

- Comparison of f/# in several laser triggered systems:
  - Z accelerator – *Tempest 10* laser with 3X beam expander, ½-m focal length lens
    - → 500 mm/15 mm = 33.3
  - HERMES III – apertured KrF beam (diameter is 2.5", but height has been reduced to 1" with apertures, creating a rectangular profile), 1 ¾-m focal length lens
    - → Min f#: 1750 mm/35.3 mm = 49.6 (f/# for height = 1750 mm/25.4 mm = 68.9)
  - New HIII Tempest system – current design calls for 3X beam expansion, 1 ¼-m focal length lens, but more expansion may be needed for better triggering

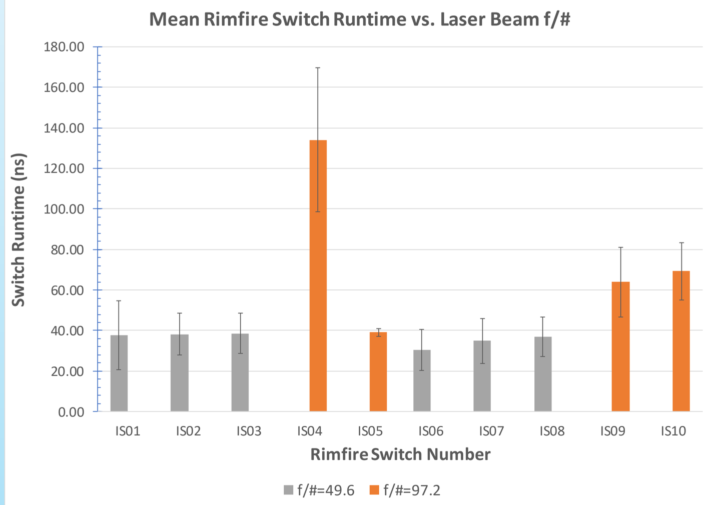
Beam Diam. (mm) \ Lens Focal Length (mm)	1750	1250
6	291.7	208.3
18	97.2	69.4
36	48.6	34.7

Preliminary Tests

- One-week trial period for the solid-state laser system was undertaken at the end of February
- Only two cabinets were installed at this time to
  - Step through the process necessary for replacing the legacy optical cabinets with the new RF enclosures
  - Complete triggering and data acquisition system development for the new lasers
  - Begin characterizing Rimfire switching performance using the lasers
- 12 "half-machine" shots were performed (only half of the HERMES III accelerator, the west side, was operated)
  - Optical setups for the new lasers used only the 1.75-m lenses, as the 1.25-m lenses had not arrived; therefore triggering was by ablation of electrode material
  - Tests included using no beam expander (6-mm-diam. Tempest beam) and a 3X beam expander (18-mm diameter)
- The Legacy KrF cabinets were reinstalled at the end of the trial period

Observations of Switch Performance

- Triggering of all four Rimfire switches was demonstrated, though runtime and std. dev. in runtime was generally longer than desired
- Preliminary test results highlight the importance of lower f/#, even though energy should be adequate
  - Command trigger with f/#=291.7 could only be obtained during one test
- Performance with a lens allowing focusing in triggered gap rather than on the far switch electrode would likely be better
  - Tempest hot spots may have been recessed within the craters created by the KrF laser beams on the far electrodes, perhaps degrading performance



Summary and Concluding Remarks

- The new HERMES III laser triggering system will be installed later this year
- This system uses ten 40-mJ solid-state Tempest 300 Nd:YAG lasers, each capable of independently triggering two (upper and lower) Rimfire switches
- Preliminary tests with two of the lasers demonstrated switch triggering, though some adjustments to the optics are needed to reduce runtime and shot-to-shot jitter

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