A Compact, TIM-Based, Pulsed-Power System for Magnetized Target Experiments on OMEGA

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A compact, self-contained magnetic-field generator was built for magneto-inertial fusion experiments on OMEGA.

Summary

- The system (MIFEDS)\(^1\) seeds a fast (~400 ns), 0.1 to 0.15 MG magnetic pulse in a cylindrical target via a double coil.

- The magnetized target is imploded by OMEGA to compress the internal magnetic flux to high values.

- The discharge does not affect the target position before the OMEGA shot.

- The upcoming experiments (November 2006) will use proton radiography to detect the compressed magnetic fields.

\(^1\)MIFEDS—Magneto-Inertial Fusion Electrical Discharge System for OMEGA
Collaborators

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Motivation

Seeding macroscopic homogeneous $B$-fields in ICF implosions can enable many MIF experiments

• The compression of the seeded magnetic field to tens of megagauss:\(^1\)
  – inhibits the electron thermal transport out of the ICF hot spot
  – can pinch the relativistic electrons generated by the ignition pulse in fast-ignition implosions.
  – provides conditions for laboratory astrophysics experiments

• Can test experimentally how magnetic fields in the corona may be affecting the inhibition of thermal flux in the conduction zone.

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\(^1\) Compressed fields of >10 MG simulated with *LILAC-MHD*, starting from 0.1-MG seed field (see N. W. Jang, JO2.00012).
Requirements

A static homogenous field is required throughout the target volume

• The small interaction volume at TCC requires low-mass, single-turn coils (low-inductance system).

• The current rise must be fast in order to minimize the action integral that determines the lifetime of the small coil (due to Joule heating).

  – seeking \( \min \left[ \int i^2(t) dt \right] \), where \( i^2_{\text{max}} \) is fixed by design

• High voltages are needed to maximize energy \( (E_{\text{stored}} = CV^2/2) \) density.

• The energy must be delivered via a low-impedance transmission line through a fast switch.
A TIM$^1$-based, fast pulser delivers energy efficiently, while reducing the transmission distance and EMI issues.

- It is a fast (150-ns-pulse rise time) capacitive discharge system that can safely store up to 130 J of energy (at 36 kV).

- A laser-triggered spark gap couples the energy into a low-inductance coil via a low-impedance transmission line.

- The device is housed in a shielded air bubble.

$^1$ TIM—ten-inch manipulator; a versatile diagnostic insertion port on the OMEGA target chamber.
The magnetic field is generated in a double-coil configuration suitable for OMEGA implosions.

- Coil separation was chosen for optimum beam illumination and to avoid possible mechanical or electrical contact with the target.

- The coil parameters are:
  - coil separation $d = 4.4$ mm
  - radius $R = 2$ mm

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$B_z$ (MG) vs. $y$ (mm)

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A seed magnetic field of 0.1 to 0.15 MG was generated with the prototype system charged to 25 to 30 kV.

\[ I_{DET}(t) = I_0 \cos^2[\theta_{rot}(t)] \]

\[ \theta_{rot}(t) = V B_z(t) d_z \]

\[ d_z = 1 \text{ mm}, V = 100 \text{ rad/MGcm} \]

\[ B_z^{\text{max}} \approx 0.15 \text{ MG}, i_{\text{max}} \approx 76 \text{ kA} \]
The target is compressed by 40 OMEGA beams while 20 are used for proton radiography.

Only about 1% of the directly deposited laser energy is intercepted by the coils.

On the timescale of the magnetic pulse (~400 ns) the target remains unaffected by the coil discharge.

- A cylindrical shell was placed between the coils to check target survivability after discharge (but before the laser shot).

- Axial compression
  - $\nu_a \text{ max} = 67 \ \mu m/\text{ms}$

- Radial expansion
  - $\nu_r \text{ max} = 68 \ \mu m/\text{ms}$

The magnetic impulse reaction time of the coils is much longer than the pulse rise time.
Proton radiography is used as the primary diagnostic in the flux compression experiments.

- Proton source is a Gaussian with FWHM = 45 \( \mu \text{m} \) (yield \( \sim 5 \times 10^8 \) p).\(^1\)

- Distance to the CR-39 detector is \( \sim 30 \) cm.

- Approximately \( 1.5 \times 10^7 \) protons are deflected by either the background (seed) field or the compressed shell.

- Approximately \( 2 \times 10^5 \) protons are deflected by the 20-\( \mu \text{m} \)-wide compressed cylindrical core.

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