An overview of diagnostic developments for M3; a 2.5 MJ, low inductance capacitor discharge machine

P. Holligan[1], L. S. Caballero Bendixsen[1], T. Clayson[1*], J. Darling[1], O. Hall[1], S. Hall[1], J. Parkin[1], G. C. Burdiak[1], H. W. Doyle[1], P. Foster[1], T. J. Ringrose[1], J. W. Skidmore[1], S. Bland[2], S. Theocharous[2]

*tom.clayson@firstlightfusion.com [1] First Light Fusion Ltd., UK [2] Imperial College London, UK

first light

First Light Fusion

First Light Fusion (FLF) is a privately funded company in the early stages of researching energy generation using inertial confinement fusion (ICF).

FLF utilizes strong shocks, driven by hyper-velocity projectiles. Novel targets are designed with the help of in-house developed hydrodynamic codes.

Electromagnetic launch at FLF

To achieve projectile velocities >10 km/s, FLF has developed electromagnetic launch capabilities over the last 2.5 years.

M1: Mega-Amp

- Designed and built in-house.
- Test bed for switches, diagnostics and electromagnetic launch.
- Low inductance capacitor discharge and Mylar insulated parallel plate transmission line.
- Total capacitance of 15.6 μF, storing 28 kJ when charged to 60 kV.
- Total inductance of ~16 nH.
- 1 MA peak current in ~1 μs rise time.

M2: CEPAGE

- Leased from ITHPP in January 2017
- Low inductance capacitor discharge and Mylar insulated parallel plate transmission line
- Coaxial multi-channel ball gap switches
- Total capacitance of 32 μF, storing 115 kJ when charged to 85 kV.
- Total inductance of ~5 nH.
- 3.5 MA peak current in ~500ns rise time.

Variations of flyer plates (shown in Fig 1) are used to achieve high velocities and drive shocks through targets.

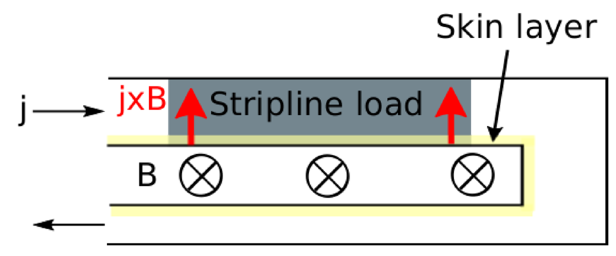

Fig. 1: Geometry of a flyer plate.

These facilities are used to benchmark hydrodynamic codes developed inhouse and used to design targets. (please see posters by D. Chapman and N. Hawker et al. for more details).

M3: a low inductance pulsed power driver

New machine built to demonstrate fusion at FLF.

Designed and built in-house with an aggressive schedule (June 2017 to December 2018).

Total of 2.5 MJ of stored energy.

Expected current >14 MA, with a ~1.5 μs rise time.

Bipolar capacitor discharge design charged to +/- 100 kV.

Low inductance achieved with parallel plate transmission line design.

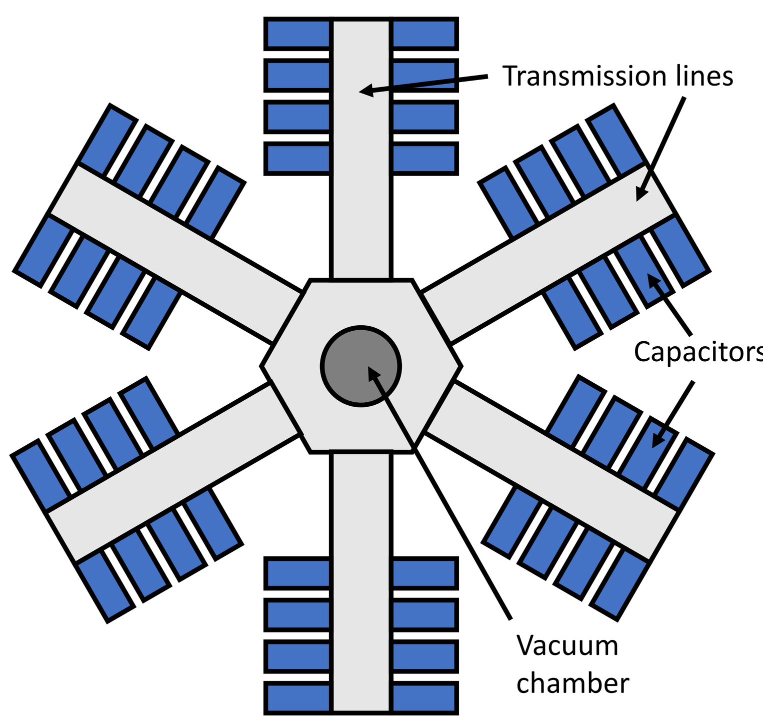

Fig. 2: Top-down schematic of M3.

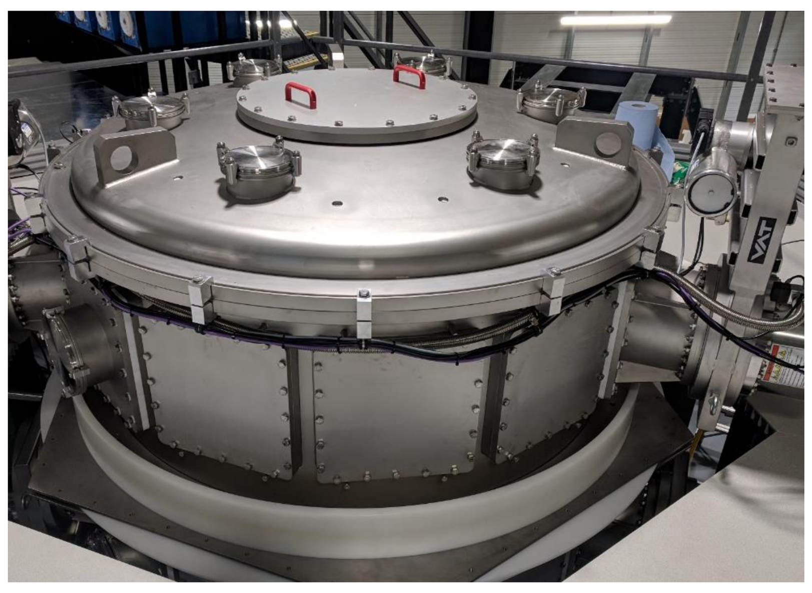

Fig. 3: M3's cylindrical vacuum chamber with a diameter of 1.7 m and height of 1.7 m (manufactured by Pfeiffer vacuum).

A total capacitance of 125 μF is achieved with 192 capacitors (manufactured by ICAR).

Upon firing, 96 ball gap switches (manufactured by ITHPP) are simultaneously triggered by a +/-90 kV LTD brick.

Mylar insulation and a unique capacitor coupling design allow for low inductance without insulating transformer oil.

Fig. 4: Panorama of M3 during construction

M3 Diagnostics

B-dot probes

- Designed and built in-house.
- Pickup coil measures changes in the magnetic field to infer the current.
- 96 probes, monitoring each switch.

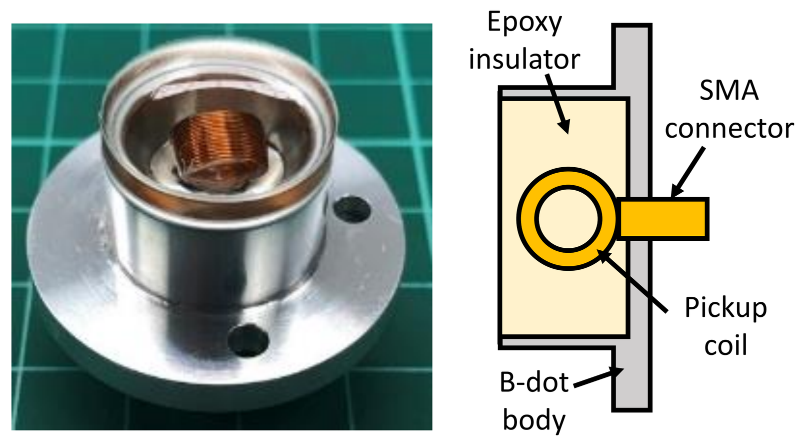

Fig. 5: B-dot probe used on M3. Left: picture of assembled B-dot. Right: cross-section of a B-dot.

V-dot probes

- Designed and built in-house.
- Capacitively coupled to measure changes in the local voltage.
- 96 probes, monitoring each switch.
- 24 probes, monitoring the transmission lines.

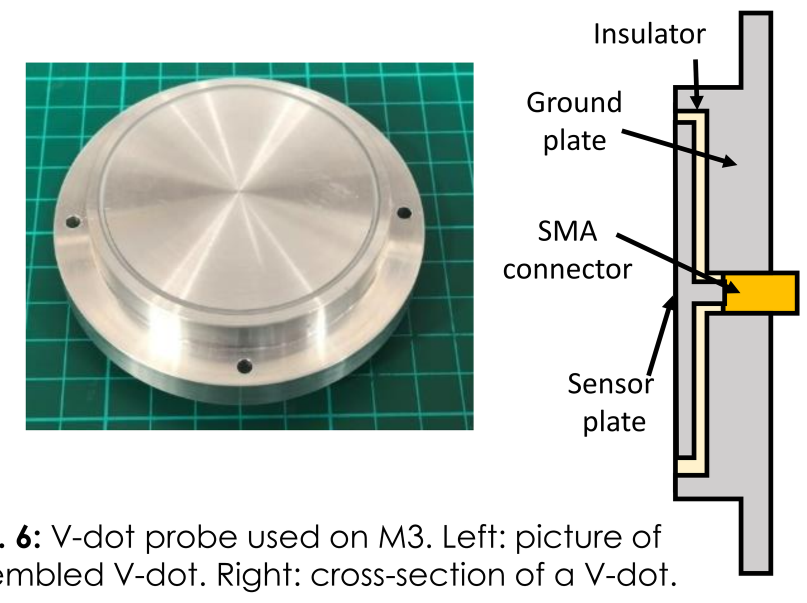

Fig. 6: V-dot probe used on M3. Left: picture of assembled V-dot. Right: cross-section of a V-dot.

Faraday rotation

- Measure change in rotation of a polarised laser, caused by the Faraday effect, to determine the local magnetic field and thus infer the current.
- Entirely fibre based with a 1550 nm laser.
- 8 channels monitoring each transmission line, the current feedthrough and the load.

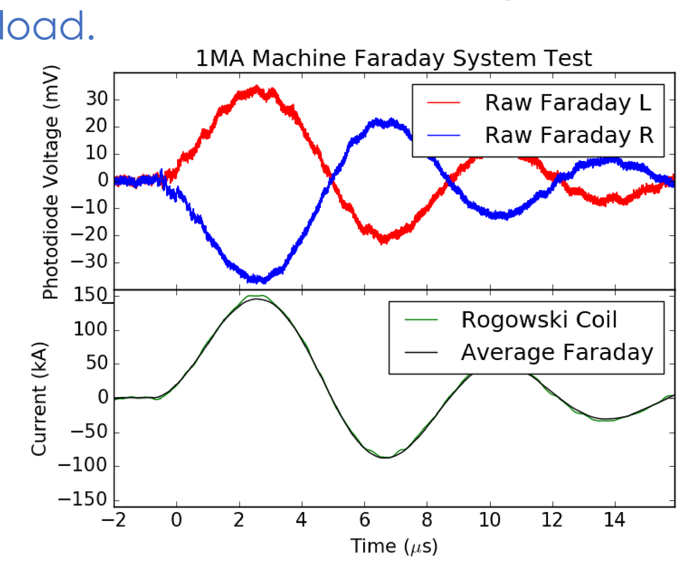

Fig. 7: Comparison between Faraday and Rogowski measurements on an M1 test shot.

Data acquisition

- 256 fast channels record Faraday rotation, B-dot and V-dot signals.
- 128 slow channels monitor the charging of each pair of capacitors.
- Data is displayed in real time on the control software.

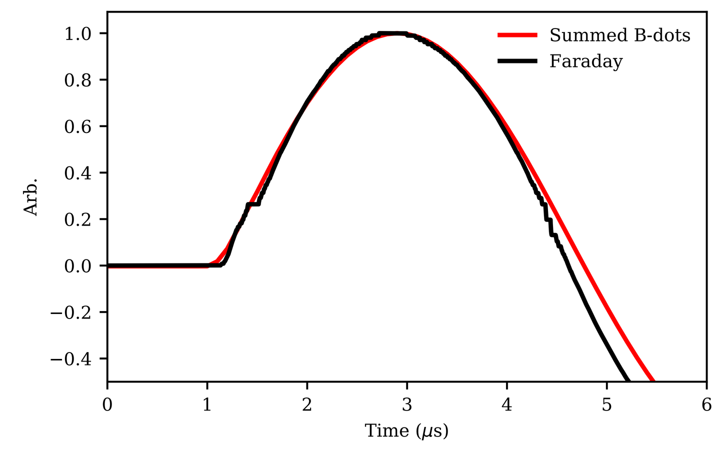

Fig. 8: Normalized Faraday current measurements compared with the normalized sum of B-dots.

Launcher and target diagnostics

(please see posters by P. Allan and G. C. Burdiak et al. for more details on experiments)

Optical imaging

- SIMX (16 frames, 3 ns exposure, 40 ns interframe, 50-100 μm resolution).
- SHIM (256 frames, 50 ns exposure, 100 ns interframe, 50-100 μm resolution).

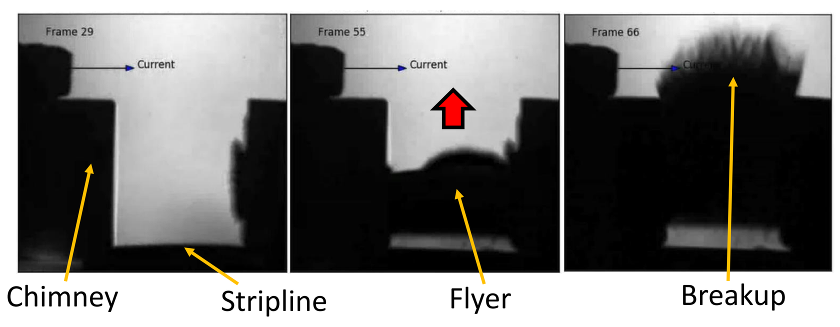

Fig. 9: Backlit images from the SHIM camera, captured from a flyer plate experiment.

VISAR

- 10 W Verdi 532 nm CW laser.
- Recorded with a Sydor Ross 2000 streak camera.
- 5 μs to 10 ns streak sweep

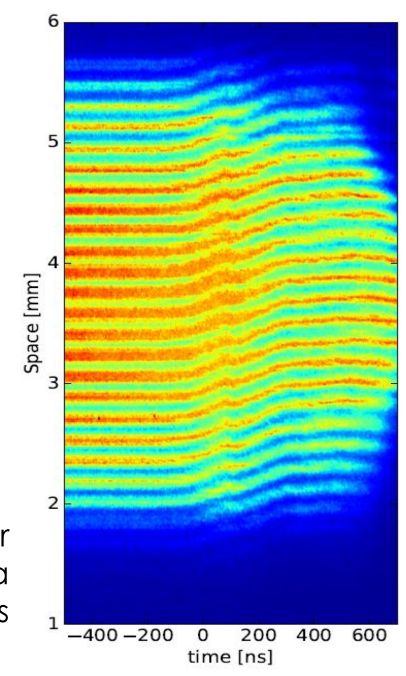

Fig. 10: VISAR image from a flyer plate experiment, indicating a velocity of 2.6-2.9 km/s

X-ray radiography

- Capable of 50-100 μm resolution with a 30 mm FOV.
- A separate X-pinch driver is used to produce X-ray source.
- Charged up to 30 kV, discharged in 20 ns.

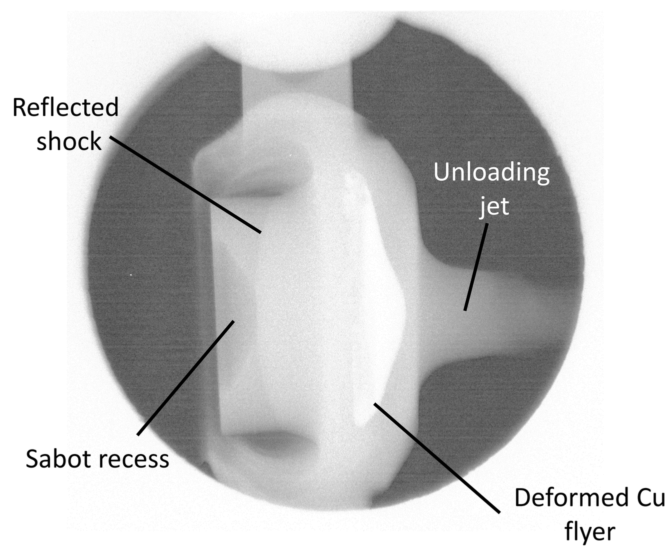

Fig. 11: X-ray radiography image of a target-load interaction.

Neutron detectors

- Plastic scintillators with PMTs, ~30% efficiency.
- Characterised with a 100 J, 10 Hz DPF (outputting ~10^5 neutrons per pulse).
- Cross calibrated with bubble detectors.

Future plans

M3 will be completed by late November and commissioned by December 2018.

Experiments are planned to start in December 2018.

Experiments on M3 will inform the design of M4, for future FLF gain experiments.

 www.firstlightfusion.com