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CRYOGENIC DEUTERIUM Z-PINCH AND WIRE ARRAY Z-PINCH STUDIES AT IMPERIAL COLLEGE

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The MAGPIE generator (2.4MV, 1.9MA) was employed to discharge currents of up to 1.4MA through cryogenic deuterium fibres of 100μm diameter and 2 cm in length with a current rise time of 150ns. Optical and X-ray streak and framing cameras and laser interferometry and schlieren were employed, and gave results similar to those found in our earlier experiments with 33μm diameter carbon or CD_2 fibres. The coronal plasma expanded with a constant velocity of $\sim 5 \times 10^4 ms^{-1}$, and $m = 0$ MHD ionizing instabilities were observed from the beginning of the discharge with an axial wavelength of about 1mm. At no stage was it possible to create a plasma in the collisionless large ion Larmor radius regime, and the results are consistent with 2-D MHD simulations with atomic physics included. Pre-ionization of the fibre by a current prepulse halves the expansion velocity, but only 1% of the fibre is ionized by this early current flow. The neutron yield of $\sim 10^9$ occurred at the later $m = 0$ disruption and from its anisotropy is associated with ion acceleration processes.

For the last 9 months experiments with MAGPIE have concentrated on wire array implosions with the objectives of understanding the basic physics of wire arrays and the resulting X-ray emission and how to couple the energy more quickly into suitable plasmas. Arrays of 1.6cm diameter, cosisting of 8, 16 or 32 equally spaced aluminium wires of diameter 15μm were used. The mass was chosen so that implosion of the wire arrays resulted in a dense Z-pinch being formed on the array axis at the moment of current maximum. The kinetic energy of the imploding ions of 10-30keV is thermalised as the plasma stagnates on the axis. The analysis of laser probing data allows the evaluation of the radial and azimuthal motion of the wire plasmas. The motion of the coronal plasma from individual wires towards the array axis was observed well before the start of the wire motion. The expansion velocity of the plasma on the individual wires is much greater towards the array axis than away from it. Preliminary experiments show that the azimuthal expansion of the coronal plasma is practically the same for different values of the current per wire but is not the same as expansion of a single wire. The azimuthal structure of the plasma at early time (before the implosion) was measured by end-on laser probing. Plasma streams from the individual wires were observed, flowing radially inwards to the array axis. This resulted in the formation of a precursor plasma on the array axis, the parameters of which were measured by laser probing and time-resolved optical and soft X-ray photography.

The collapse of the wire array is found to be non-uniform and time resolved X-ray framing images show the appearance of correlated bright spots on wires at 160ns, just prior to the collapse of the wires. This is indicative of an instability in the global magnetic field of the array. Spectroscopic analysis of the X-ray emission from the imploded plasma shows that it is predominantly from hydrogen- and helium-like alumimium and line ratio measurements give time temperatures of the plasma of between 400 and 600eV. Experiments are also being carried out in which the wire arrays are collapsed onto a target fibre (Mg or CD_2) located on the array axis.

The experimentally observed features from low number wire arrays are distinctly three dimensional. We have therefore been developing a three dimensional resistive MHD code for the simulation of wire arrays. Two-dimensional simulations have shown that in order to follow the spontaneous evolution of the $m = 0$ instability from a noise perturbation to long wavelength requires 10μm spatial resolution. Mapping the entire wire array onto a 3-D cubic grid with this resolution would require $\sim 10^9$ cells. Therefore an alternative approach is adopted where the initial phase of individual wires prior to their interaction with neighbouring wires is modelled in 2-D (r,z) simulation and the results are then used as the initial starting conditions for a 3-D (x,y,z) simulation with 100μm cells. Partially degenerate equations of state and transport coefficients for the electron fluid have been added to the 2-D code to allow simulation of metal wires from 'cold-start' conditions, showing that a significant fraction of the mass of the wire remains in the solid phase for the majority of the experiment. Three-dimensional results show that the symmetry of implosion is strongly affected by the level of ionization provided by the 2-D code.

The combined Rayleigh-Taylor/MHD instability has been studied in a 2-D simulation of an imploding, diffuse Z-pinch. The classical R-T prediction gives a good agreement for short wavelength modes occurring in the shocked region of a characteristic thickness, while long wavelengths have a reduced growth rate.

A heuristic model dividing the wire array behaviour into 4 phases can successfully reproduce many features of the experiments at IC and Sandia[2]. Initially the n wires explode and are unstable in an uncorrelated way. At merger into a shell the level of seed perturbation varies as $n^{-1/2}$ and during the subsequent shell implosion Rayleigh-Taylor instabilities grow linearly and non-linearly. The final pinch diameter and instability level is found, and during an MHD bounce time the ion kinetic energy is converted via viscosity and equipartition to electron heating, further ionization and X-radiation.

To understand further the basic physics of wire arrays, experiments have also been undertaken with single and double wires of aluminium[3] or tungsten on the IMP generator delivering up to 160kA in 6.5ns. Expansion velocities, instabilities and bright spot formation were recorded for various diameter fibres. Tungsten has expansion velocities in the range $5 \pm 3 \times 10^3$m/s while aluminium expands at least a factor of 2 faster. Short wavelength perturbations appear at about 8ns for aluminium compared to 20ns for tungsten pinches, while bright spots appear at 40ns and 60ns respectively. Hard X-rays above 8keV are only observed for tungsten wire pinches, apart from anode emission which occurs for both.

The separation of pairs of 15mm diameter aluminium fibres was varied from 300μm to 1.5mm. The plasma dynamics were studied with schlieren photography with a 7ns pulsed ruby laser. In addition, four frame GOI, time integrated pinhole camera, optical streak camera, crystal spectrometer and filtered PIN diodes were used to monitor optical and X-ray emission. Expansion of the wires is greater in the region between the wires and is with uncorrelated axial structures; in contrast the structures surrounding the wires are spatially correlated.

Further theoretical work on the stabilising effect of sheared axial flow has been carried out in the MHD regime[4] where residual low growth is always present. In a hybrid code[5] with particle ions in the large ion Larmor radius regime, a sheared axial flow is naturally set up during implosion accompanied by anomalous current penetration, for an ion Larmor radius up to one tenth of the pinch radius.

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