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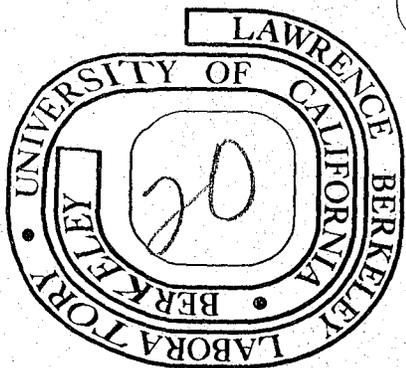A.H. Boozer, M.A. Mostrom, and N.T. Gladd

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TORMAC CONFINEMENT, THEORY AND EXPERIMENT*

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Tormac is a stuffed toroidal line cusp: the magnetic field is divided into two distinct regions, i.e., an outside "sheath" layer where the plasma is mirror-confined on open field lines, and an internal high-β region of closed nested flux surfaces. The sheath is arranged with the appropriate curvature to ensure absolute MHD stability everywhere. The bulk of the plasma is maintained on closed flux surfaces as in a typical toroidal configuration, but with enhanced MHD stability due to the external field shaping.

Experimental results on a toroidal "bicusp" (Tormac IV) will be reported. This device has a boro-silicate glass chamber and holds a plasma with an aspect ratio of 4 and a major diameter of 35 cm.

The magnetic field is pulsed, with a 7 μ sec rise time and a 100 μ sec decay time. The intensity is adjustable up to 1 Tesla at the plasma surface and 3 Tesla where the cusps intersect the glass wall. The plasma is produced from a 0.05 Torr mixture of hydrogen and helium in <u>situ</u>. Before ionization, a 300 Gauss toroidal magnetic field with a 100 micro-second period is established in the center of the vessel.

A 2 megacycle preionizer is used to break down the gas. At the same time, a toroidal current is induced in the plasma with a peak value of 40 kA and a frequency of 100 kHz. This pinch current is calculated to satisfy an equilibrium which is very slightly unstable. However the growth time is longer than 1/4 period of the driving system and is not observed before the bicusp field is applied.

Twenty five microseconds after preionization, the plasma is compressed and in part heated by the application of the containing bicusp magnetic field. Without supplemental heating, ion temperatures of the order of 100 eV are measured spectroscopically.

Normally, during the latter stages of the compression period, a toroidally symmetric magneto-acoustic wave is launched into the plasma using a single-turn coil around the outside of the glass vessel. The wave is launched from a generator which produces a pulse of 2 MHz power 5 cycles long and containing about a kilojoule of energy. Ion temperatures of 300 eV and electron densities of 4×10^{15} are measured just after compression. Electron temperatures using Thompson scattering are in the process of being taken.

Detailed profiles of the D_α, D_β, and He 4686 lines are measured using a tomographic process which reconstructs the emitted light as a function of position, intensity and time. The measurement has a resolution of 2 cm spatially, .3A spectroscopically, and .5 microseconds in time. Temperatures and densities

are calculated from line shapes. In the case of He 4686 line intensities are measured over two orders of magnitude. In the case of D_β the line width is checked at the 1/8 peak intensity points.

A well documented set of measurements has been carried out for a particular case in which the plasma starts with an ion temperature of 180 eV and density of 4×10^{15} ions/cm^3. A local beta of the order of .5 is calculated from the spatially resolved spectroscopic data. A HeNe interferometer is used to corroborate the density measurements, and magnetic measurements of the plasma beta are used to determine an energy confinement time of ∿ 100 microseconds.

Experimental results cannot be explained on the basis of collisional cusp theory and are consistent with a theory of adiabatic trapping of particles in the sheath.

In our theoretical investigation, we have examined the consequence of the open field lines in the sheath, where Tormac confinement is by magnetic mirroring. This leaves the system susceptible to loss-cone instabilities, and in particular to the drift cyclotron loss-cone mode (DCLC). The unique feature of the Tormac sheath, compared to a standard mirror, is that the magnetic shear scale-length and pressure gradients can be of the order of an ion Larmor radius, which may improve the stability properties of the DCLC mode. We have initiated theoretical studies of the effect of shear on the DCLC mode and currently we have completed calculations in the limit $\rho/R_p < 1$ where R_p is the cross magnetic scale length and ρ is the ion Larmor radius. We find that at low beta, shear has a destabilizing influence on the DCLC mode while it is stabilizing when beta is of order unity. Stability is achieved for ρ/R_p ∿ 1, when R_p/L_S ∿ 4 where L_S is the shear scale-length. As a consequence, in the high-beta region of the sheath, the shear can be stabilizing while in the lower beta region of the sheath instability can be expected to arise. This result is still preliminary, as for Tormac it is necessary to consider ρ/R_p ∿ 1 and this calculation is currently under investigation.

In the event the sheath remains unstable even with shear in the low beta region, alternative processes are needed to suppress the level of DCLC noise. The most straightforward approach is to run in a manner similar to the current 2X-IIB experiment where stabilizing warm plasma is supplied. Optimum heat confinement in the presence of the DCLC instability will occur if $T_e \simeq 300$ eV. An alternative option, already experimentally demonstrated in several experiments, is to produce very hot electrons in the sheath which can quench the DCLC mode.

To indicate the applicability of Tormac as a practical reactor, a set of design parameters have been calculated as a function of the possible sheath conditions. If there are no instability problems and the sheath can be thermally insulated from the wall then an ignition reactor can be reached with a 15 k Gauss containing field and a 2 m minor plasma radius. If instabilities or thermal conductivity force a reactor to run with 300 eV electrons in the sheath then 50 k Gauss is required to contain the plasma. However, if sheath electrons are heated to near relativistic temperatures then not only are instabilities surpressed, but containment is improved to the point where an ignition reactor can be reached even with advanced fuels.

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