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EXPERIMENTAL AND THEORETICAL DEVELOPMENTS IN TOROIDAL CUSP CONFINEMENT (TORMAC)

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EXPERIMENTAL AND THEORETICAL DEVELOPMENTS IN TOROIDAL CUSP CONFINEMENT (TORMAC)*

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Abstract: Stable hydromagnetic equilibrium has been demonstrated in a two-pole toroidal cusp experiment at $\beta \approx 1$ ($n_i \approx 2 \times 10^{15}$ cm^{-3}, $kT \approx 10$ eV). Higher temperatures are expected in a larger device, under construction, in which wall contact is avoided. Theoretical considerations predict both stability and good confinement in the long mean-free-path limit.

Levine and his coworkers have described the confinement of a high-beta plasma in the Tormac device.[1-3] In this configuration the bulk of the plasma is contained within a toroidal volume of closed magnetic flux tubes. The entire plasma is surrounded and supported by an outer region or so-called sheath region characterized by strong poloidal field components produced by external coils in an annular cusp arrangement. Particles with guiding centers in this outer sheath region are confined on the open field lines by mirror-like[3] reflections from the peak magnetic fields near the cusp. Thus each cusp has associated with it a hole or loss-cone in velocity space through which particles are lost. In a toroidal coordinate system with toroidal symmetry there is a conservation of the generalized angular momentum of a particle. This leads to a displacement of the hole in velocity space at each cusp as a function of its position relative to the major radius. Since each sheath particle may have access to all cusps the displacement of the loss hole in velocity space of one cusp relative to another cusp leads to an increase in the overall particle loss rate. To eliminate this problem the two-pole or "Bicusp" shown in Figure 1, has been developed. MHD equilibria for the Tormac Bicusp are readily found with the help of an electrolytic plotting tank as an analogue.

We also require for MHD stability that the curvature of the poloidal field, K_p, be such that $K_p > \left(B_T/RB_p\right)\cos\eta$ where η is the angle between the plasma surface normal the major radius vector R of the toroid. Cos η is positive on the outside region, negative in the inside region. Satisfying this inequality insures that the center of curvature of any magnetic field line on the surface of the plasma lies outside the plasma. Thus the geometry is a true cusp and an absolute minimum-B.

A Tormac Bicusp has been constructed using a pyrex chamber with a .5 meter outside diameter. Within this bottle the plasma has a cross section of about 7 cm with a major diameter of about 25 cm. The Bicusp magnetic field is created with one winding which gives both poloidal and toroidal components. In addition to the Bicusp field, a toroidal bias magnetic field, a high frequency and a low frequency preionizing field, both with poloidal components only, and a high frequency heating field with poloidal components are provided.

In the experiment a low pressure 10 millitorr helium-hydrogen mixture is ionized *in situ*. The toroidal bias magnetic field is trapped within the plasma. To obtain full ionization a hot filament and two discharge capacitor systems are all used. The Bicusp magnetic field with a peak value of 5 kilogauss is created by a crowbarred capacitor discharge with a rise time of either 6 μsec or 8.5 μsec depending on system connections. The plasma is observed to compress by about a factor four, and a spectroscopically determined temperature after compression of about 7-10 ev is obtained.

At these temperatures and density the plasma containment time is observed to be greater than 200 μ seconds. Under these conditions plasma loss is by diffusion along field lines. However because recombination and interdiffusion is very slow at the wall the plasma life time is long. Unfortunately, this close contact with the wall severely restricts the attainable temperature.

A larger chamber is under construction in which considerably more space between the mirror regions and the cold walls is provided. It is expected that in this version significantly higher temperatures can be achieved so that confinement by a nearly collisionless sheath can be tested.

When a future collisionless high-temperature plasma is confined in this way, guiding center drifts will tend to carry all particles to the boundaries. Thus the loss-cone distribution would be communicated throughout the region with closed flux tubes unless a magnetic rotational transform or a mechanical mass rotation about the minor axis is superimposed. In the case of purely circular field lines with radius R in the absence of cross-field diffusion the number of particles n(R) on a flux tube must remain constant during internal rotation:

$$n(R)/n(R_0) = R_0B(R)/RB(R_0)$$

where R_0 is an arbitrary radial position within the plasma. Thus the density and therefore the pressure must vary with R. The equilibrium is maintained by internal poloidal currents in this case which modify the toroidal field B(R). For large aspect ratios only slow rotation is needed and centrifugal effects can be neglected in a first approximation. The conditions for the required dynamic equilibrium have been worked out both for the one-fluid MHD model and for the double-adiabatic CGL plasma. In all cases the resulting density profiles are found to be marginally stable towards m = 0 perturbations, which is not surprising because the proscribed slow rotation is itself a pure interchange process. It is concluded that a high-temperature Tormac is an interesting exploratory concept for controlled thermonuclear fusion.

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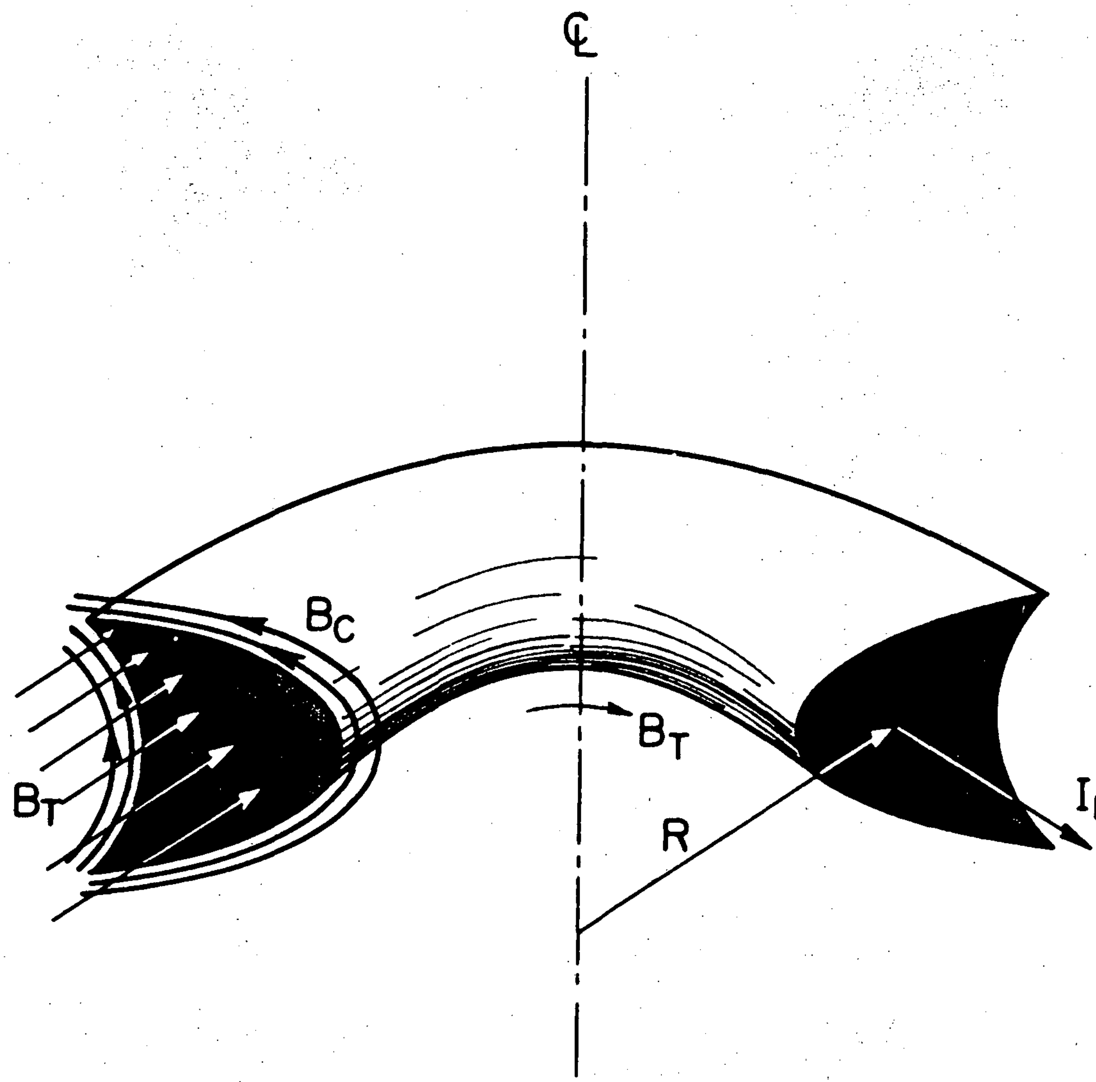

Figure 1: Tormac in the Bicusp Configuration

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