Some physics issues in magnetised liner fusion

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Some physics issues

- Electrothermal instabilities
- Theta-pinch rotation and instabilities
- Fast loss of highest energy electrons
- Fast loss of 100keV ions

Electrothermal instabilities

(a) current-driven on outside of liner

$$B_\theta \Rightarrow j_z \Rightarrow k_\theta$$

(b) current-driven on inside of liner

$$B_z \Rightarrow j_\theta \Rightarrow k_z$$

(c) heat-flow driven q_r

Conditions: (i) $T_e \le T_{critical} = \left[\frac{4n_e\alpha^c}{3\mu_0\kappa^c}\right]^{1/4} \left(\frac{Z\ell n\Lambda_{ei}}{9.7\times10^3}\right)^{1/2}$

(ii) $j > j_{critical}$ such that $T_e > 1.32T_i$

References on Electrothermal instabilities

in fully ionised plasma:

M.G.Haines, *J.Plasma Phys*.**12**, 1 (1974*)(current-driven*)

M.G.Haines, *Phys.Rev.Lett*. **47**, 917 (1981)(*heat-driven*)

Partially ionised plasma *(see references therein)*:

A.H.Nelson & M.G.Haines, *Plasma Phys*.**11**,811 (1969)

Fully ionised in a diffuse pinch j_z with $B_z >> B_\theta$:

A.Tomimura & M.G.Haines, *J.Plasma Phys*.**23**,1 (1980)

M.G.Haines & F.Marsh, *J.Plasma Phys*.**27**, 427 (1982) (*finite amplitude filaments*)

Theta-pinch rotation

- 6 mechanisms lead to rotation; reviewed in *Advances in Physics* **14,** 167 (1965).
- Most likely mechanism in MagLIF is due to early wall interaction in one ion Larmor period;
- Demonstrated via Doppler shift by H.Witulski (Jülich report 1183 (1975)) and reported in M.G.Haines, *Nucl.Fusion* **17**, 811 (1975)
- m = 2 instability grows and terminates the pinch.
- Finite Larmor radius effects can stabilise weak rotation; E.C.Bowers & M.G.Haines, *Phys.Fluids* **11**, 2695 (1968) & **14**, 165 (1971)

Fast electron axial heat loss

Heat flow q_e with no current, parallel to magnetic field

$$Q = \frac{q_e}{n_e m_e v_T^3} = \frac{2t}{3\pi^{1/2}} \int_0^{V_a} (4V^9 - V^{11}) \exp(-V^2) dV$$

where $V = v/v_T$. V_a is infinity for total heat-flow, BUT

V_a^2	=	7	8	9	10	11	12	∞
$Q(\%)$	=	18.8	44.2	64.1	78.2	87.3	92.9	100

Up to V_a^2 =6.32 the heat flow is negative to zero. The heat is carried essentially by < 5% of the electrons with energy ~ $10T_e$ and a collision-length 100×m.f.p.

Axial loss of 100keV ions

Similar arguments apply to energetic ion loss where we require a temperature of 10keV but the important ions are those with energy > 100keV for fusion reactions. Their collision length is 100×mean-free-path. For a density of 10^{28} m^{-3}, 100keV ions have a collision length of 1.88cm, comparable with the length of the confined plasma, and will be lost in 3.6ns from a 2cm column.