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THE LIVERMORE SUPERCONDUCTING LEVITRON

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PLASMA HEATING AND CONFINEMENT IN THE LIVERMORE SUPERCONDUCTING LEVITRON

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ABSTRACT

Stable confinement of approximately isotropic hot-electron plasma is observed for $\beta \leq 0.1$ and $\beta_\phi = \beta B^2/B_\phi^2 \leq 10$. Confinement at large $\beta_\phi$ without anomalous loss is found to result from a cold-plasma background with $n_{ec}/n_{eh} = 10^{-2}$. Heating of dense plasma ($n_{ed} = 10^{11} - 5 \times 10^{12}$, $T_{ed} = 10-20$ eV) occurs by thermalization with the hot-electron plasma at a collision-determined rate without significant anomalous loss of hot electrons.

This paper presents results of plasma heating and confinement studies in the Livermore Superconducting Levitron (SCL). For plasma heating kinetic energy is first stored in the confinement region in hot electrons produced by microwave heating, and then dense plasma is introduced and is heated in situ by thermalization with hot electrons. Primary emphasis here is placed on the properties of the hot-electron plasma since it provides a high $\beta$, collisionless plasma for confinement studies.

The SCL device is described in (1). The minimum-B poloidal field configuration (Fig. 1) is used with the field strength adjusted as shown to provide electron-cyclotron resonance with heating power at $f = 10.6$ GHz; typically $I_{Ring} = 175$ kA-turns and $I_z \leq 240$ kA-turns. Diagnostics consist of x-ray measurements, cold plasma temperature measurements using a Langmuir probe at the plasma boundary, a plunging probe calorimeter (Fig. 1), and measurements of the $\phi$-directed diamagnetic current $J_\phi \propto \beta$ by a Rogowski loop.\footnote{Work performed under the auspices of the U.S. Atomic Energy Commission.}
Hot-electron plasma is formed by applying 10.6 GHz heating power (1-10 kW) for several seconds with initial gas pressure ranging from background $p_0 = 10^{-9} - 10^{-8}$ torr to $5 \times 10^{-6}$ torr He. Typical parameters are $n_{\text{shot}} = 5 \times 10^9 - 5 \times 10^{10}$, $T_{\text{hot}} = 100-500$ keV, and $\beta_{\text{max}} \leq 0.1$. Depending on the toroidal field $B_\phi$, background neutral density, and cold plasma density $n_{\text{ec}}$, $\beta$ decays at a rate $\tau_\beta$ determined by collisions as shown in Fig. 2. The plasma isotropy measured with the plunging probe is found to be

$$\frac{(n_{\text{passing}})_{\text{observed}}}{(n_{\text{passing}})_{\text{isotropic}}} = 0.5-0.8 \quad \text{for} \quad I_Z \leq 60 \text{ kA-turns}.$$  

For $60 \text{ kA} < I_Z < 240 \text{ kA}$, the observed ratio is less than 0.1 if mostly low Z background gas is present ($H_2$, $He$). During initial clean-up operation, when gas released from the walls forms the background pressure, $n_{p0}/n_{p1} = 0.5-0.8$ for all $I_Z < 240 \text{ kA}$.

The value of $\beta$ established during heating is insensitive to $I_Z$ so that for $I_Z \leq 100 \text{ kA-turns}$ the toroidal $\beta_\phi = \beta B_\phi^2/B_\phi^2$ is in the range $\beta_\phi = 1-10$. The existence of large $\beta_\phi$ in violation of the Suydam shear-stabilization criterion $[(dI/dr)/I]^2 > 4(dp/dr)(B_\phi^2/2\mu_0)$ is due to cold plasma. During
heating \( n_e = 5 \times 10^{11} \text{ cm}^{-3} \) is maintained while after heating \( n_e \) is determined by \( p_0 \). For low \( p_0 \), \( n_e \) decreases to several \( \times 10^{10} \text{ cm}^{-3} \) in a few hundred \( \mu \text{sec} \), and anomalous loss of \( n_{e\text{hot}} \) occurs until a stable value of \( n_e/n_{e\text{h}} \) is achieved. By varying \( p_0 \) immediately after heating, \( n_e \) can be changed independently of \( n_{e\text{h}} \) and the marginal stability curve shown in Fig. 3 obtained. The insensitivity to \( I_z \) (at low \( I_z \)) shows that shear effects are unimportant. No appreciable change in \( n_{\text{passing}}/n_{\text{trapped}} \) is observed after anomalous loss, suggesting MHD interchange rather than trapped particle instability. In addition to the above instability, anomalous loss of \( n_{e\text{h}} \) occurs as the plunging probe passes through the outer band of flux surfaces and passing electrons are removed. This observation suggests that for the plasma parameters studied, instabilities can occur if the hot electron pressure is made sufficiently anisotropic.

Tests of dense plasma heating have been made for \( n_{ed} = 10^{11} - 5 \times 10^{12} \text{ cm}^{-3} \) by injecting a 50 \( \mu \text{sec} \) puff of \( H_2 \) or He after heating. No appreciable anomalous
loss of energy in energetic electrons has been observed and heating of the dense plasma occurs at a rate determined by collisions. Plasma temperature $T_{ed} = 10$–$20$ eV has been obtained.

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REFERENCES


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