OBSERVATION AND CONTROL OF RESISTIVE WALL MODES*

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Stabilization of low-n kink modes by a conducting wall is crucial for high beta, steady state “advanced tokamak” scenarios. Operation at high beta allows a more compact and economical fusion plasma with a large fraction of bootstrap current. Good alignment of the bootstrap current with the equilibrium current density profile, important for minimizing the requirements on external current drive systems, is achieved with broad current density profiles and broad pressure presdsure profiles. Such current density profiles have a low beta limit in the absence of a wall, but strong coupling to a nearby conducting wall can improve the stability limit by as much as a factor of 2 or 3 [1].

Two approaches to achieving long-time scale stabilization with a real, finite conductivity wall are being considered: plasma rotation and active feedback control. Ideal MHD theory predicts that for a plasma which would be stabilized by an ideal wall, non-zero wall resistivity leads to an unstable “resistive wall mode” with a growth time on the order of the wall’s magnetic field penetration time τ_W and a real frequency $\omega \sim \tau_W^{-1}$, and which is not stabilized by sub-Alfvenic plasma rotation. However, more detailed theories show that the addition of dissipation in the plasma allows stabilization by sub-sonic toroidal rotation [2, 3]. Furthermore, external kink

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modes can drive islands in a resistive plasma, allowing stabilization by plasma rotation frequencies as low as $\omega_{\mathrm{rot}} \sim \tau_{\mathrm{w}}^{-1}$.[4, 5].

DIII–D experiments [6] confirm many of the important qualitative features of these more recent theories. In discharges with broad current density profiles, beta values reach up to 1.4 times the ideal n=1 kink mode limit calculated without a wall, but remain within the stable range calculated with an ideal wall at the position of the DIII–D vacuum vessel. Beta greater than the no-wall limit has recently been sustained for up to 200 ms, much longer than the wall penetration time $\tau_{\mathrm{w}} \leq 2$ ms, which indicates that the resistive wall mode has been stabilized. As the rotation slows, these plasmas are typically terminated by an m=3, n=1 mode which has a growth time of 2–8 ms and a real frequency $\omega \sim \tau_{\mathrm{w}}^{-1}$, as expected for a resistive wall mode, and rotates in the electron diamagnetic direction. The mode begins to grow as the plasma rotation at the q=3 surface decreases below about 1 kHz, consistent with a loss of rotational stabilization. A similar critical rotation frequency is observed when the rotation rate is modified through magnetic braking by an applied magnetic error field.

At present, the experimental data do not clearly distinguish the predicted stabilization mechanisms. The observed critical rotation frequency is somewhat larger than the prediction $\omega_{\mathrm{rot}}\tau_{\mathrm{w}} \sim 1$ of theories which include driven islands, but preliminary data from Electron Cyclotron Emission and Beam Emission Spectroscopy measurements show evidence of island formation at the termination of some wall-stabilized discharges. The global nature of the observed mode suggests that the much more rapid central rotation of 10–20 kHz could also contribute to stabilization. More detailed measurements of the mode structure and its time evolution, in comparison to theory, should help to distinguish the predicted stabilization mechanisms.

The slow growth and rotation of the resistive wall mode should permit active feedback stabilization by non-axisymmetric coils outside the vacuum vessel. Several approaches have been proposed, including the “smart shell” where the feedback control is designed to maintain a net zero radial magnetic field at the resistive wall, and the “fake rotating shell” in which a phase shift applied to the response mimics the effect of a rotating wall. These schemes will be tested in active control experiments which are planned for DIII–D, initially using the existing error field coil (C–coil). A set of six midplane saddle loops for mode detection are being installed, matched in geometry to the six toroidal segments of the C–coil. Preliminary data on the coupling of the resistive wall mode to these new loops and to the C–coil will be presented.

[1] TURNBULL, A.D., et al., Proc. 17th Int. Fusion Energy Conf. (International Atomic Energy Agency, Vienna, 1997) Vol. II, p. 509.
[2] BONDESON, A., and WARD, D.J., Phys. Rev. Lett. **72**, 2709 (1994).
[3] CHU, M.S., et al., Phys. Plasmas **2**, 2236 (1995).
[4] FINN, J.M., Phys. Plasmas **2**, 198 (1995).
[5] BOOZER, A.H., Phys. Plasmas **2**, 4521 (1995).
[6] TAYLOR, T.S., et al., Phys. Plasmas **2**, 2390 (1995).