OPTIMIZATION OF CONFINEMENT IN TOROIDAL SYSTEMS: STUDIES OF TOKAMAKS AND ELMO BUMPY TORUS*

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1.1 Tokamak Theory

The Oak Ridge Tokamak Theory team has focussed its work in the past several years on understanding the:

- Neoclassical transport of ions and impurities including effects of neutral injection,
- Kinetic theory of anomalous electron thermal conduction, energetic particle populations and alpha particle induced phenomena
- Beta limitations from ideal MHD processes,
- Plasma disruptions and phenomena resulting from the non-ideal MHD theory of Kink Tearing modes, and
- Unified simulation of transport phenomena including atomic physics, impurities, beams and enhanced transport processes from resistive MHD instabilities.

From a large number of specific studies, this discussion will single out for further description, six topics included in Section 2.

1.2 ELMO Bumpy Torus (EBT) Theory

The Oak Ridge EBT Theory team has focussed on analogous key issues:

- Control of particle confinement by field shaping,
- Neoclassical particle transport and development of the ambipolar potential,
- Stability of the toroidal plasma and hot electron ring system,
- Physics of the electron ring,
- Analysis of microwave propagation and absorption, and
- Unified simulation of transport phenomena including atomic physics, microwave heating, and self-consistent determination of the ambipolar potential.

Section 3 will summarize the most important recent advances in EBT understanding.

2. Specific Tokamak Theory Research Advances

2.1 The observed anomalous electron thermal transport processes are interpreted by S. P. Hirshman and K. Molvig (MIT) as a consequence of stochastic magnetic fields calculated in a strong turbulence theory of drift waves in a sheared magnetic field.

2.2 Alpha particle density gradients and anisotropies in fusion plasmas can cause unstable coupling to shear Alfven waves. The importance of the resulting instabilities is being assessed.

2.3 Resistive tearing modes are found in a moderate β (α a/R $\equiv$ 1/A) theory to have reduced linear growth rates when the cross section of the discharge is elongated; however, if major disruption occurs because of nonlinear coupling of nonlinear M/N = 2/1 and 3/2 modes, the onset is hastened by the elongation.

2.4 Beta limitations predicted by ideal MHD kink and ballooning mode codes also are found to depend strongly upon elongation η. For η = 1.7 in a D-shaped plasma, the critical β has been found to be as high as 0.4/A, provided ballooning modes with N > 10^2 are discounted. In certain circumstances, the corresponding plasma profiles could be in resistive equilibrium and would then be consistent with long-pulse operation.

2.5 The confinement of energetic particles in non-axisymmetric fields has been systematized and an improved Hamiltonian formulation of guiding center motion has been obtained. Improved bundle divertor geometries have been found in which the disturbance of energetic ion and alpha particle orbits is substantially reduced.

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2.6 Transport simulation modeling now includes analysis of the ideal MHD ballooning criterion, yielding the dynamics of the regimes of unstable contribution to the modes. Application to high beta experiments in ISX-C shows that ballooning should be observed throughout long periods of the discharges. Since measured confinement time apparently do not change when this happens, it will be necessary to re-examine any restrictions based on the modes for operation of advanced tokamaks

In summation, tokamak theory and its comparison with experiments continue to hold promise of improvements for the conceptual design of advanced designs and reactors.

3. Specific EBT Theory Research Advances

3.1 Confinement optimization by shaping of the vacuum magnetic fields holds the potential for partially compensating toroidal curvature effects. Lifetime increases up to about a factor two appear feasible.

3.2 The hot electron rings and the warm toroidal plasma in EBT's tend to stabilize each other; however, considerable uncertainty remains for the maximum beta value stable within simple theoretical models. Pessimistic assumptions yield values as low as 10%, while optimistic estimates yield $\beta_{plasma} \sim \beta_{rings}$ which can be as high as ~50%.

3.3 Power balance for the hot electron rings, even when stable, involves a delicate balance between drag losses at low ring energy and synchrotron losses at high energy. Detailed calculations yield important but acceptable levels of energy drain.

3.4 Transport simulation modeling of EBT has undergone very large increase in realism of the treatment during the past year. An improved hydrogen recycling model and inclusion of more accurate ion transport coefficients lead to generally satisfactory agreement between neoclassical predictions and the actual data. Interpretation of ion transport is complicated by a measured high energy tail which could be understood either as a result of orbit losses at high energy or by "in situ ICRH."

Although the level of support is not high, the state of EBT theory has advanced very rapidly during the last two years and the concept remains a very promising alternative to the tokamak approach.

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Section

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