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Department of Nuclear Engineering

Progress Report
MICROINSTABILITIES IN INHOMOGENEOUS PLASMA

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Terry Kammash

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Progress Report

INTRODUCTION

A number of investigations relevant to both confinement physics and reactor studies have been initiated or continued in the period since the last progress report. In terms of relevance to CTR research these problems will be classified and discussed under three major categories: Toroidal confinement; open-ended confinement, and reactor-related studies. In each case the important results obtained thus far will be presented and a brief discussion of future work in the subject itself or in a related area will be put forth.

I. Toroidal Confinement Studies

A) Runaway Electrons in the ORMAK device.

Relativistic Electrons have been observed in the ORMAK device in Oak Ridge as well as in many other Tokamak devices throughout the world. These particles seem to occur only when the plasma impurity level is sufficiently high and the direction of the applied electric field is properly chosen. The dependence on the electric field direction has been explained by Rome (ORNL - TM3880, 1972) and the dependence on the plasma impurity level can be attributed to the lower plasma skin time which leads to a more rapid penetration of the induced electric field into the initial, low density plasma. In this research we examine the theory of production and acceleration of runaway electrons and compare the results with ORMAK experimental data by means of a parameter study. Two free parameters were used in the analysis: the radius of the current-carrying region, and the density of the runaway electrons. A range of values of density and radius that agrees with the experimental data has been found and the results are found in a paper recently submitted for publication in Nuclear Fusion. The interesting feature of this parameter study is

that it predicted a radius which would imply that the runaway electron discharges were attaining low values of the safety factor q . These results motivated the following work which we plan to pursue in the immediate future: a) an examination of the runaway electron drift orbits to follow in time the size (or radius) of the current-carrying region, and b) a study of the MHD kink mode instability in the presence of runaways and velocity shear.

B) MHD Equilibria of Toroidal Plasma with Non-Circular Cross Sections.

This investigation is aimed at studying the MHD equilibria of Toroidal plasma situated in a magnetic field with single non-planar axis with variable shear and curvature at high values of β . The plasma is taken to have a non-circular cross section (i.e. elliptically or triangularly deformed) through which a current of flat density profile flows. Equilibria of the Tokamak or French Harmonica types are examined as special cases of the general class and it is shown that for a given longitudinal current and magnetic shear the effect of triangular deformation on the limiting value of β is weak and can be neglected. On the other hand vertically elongated elliptical deformation of the plasma cross section is shown to lead to an increase in the value of β relative to that of a circular cross section. In the absence of longitudinal current it is shown that equilibria exist only at a low value of β . These preliminary results have been submitted for publication in plasma physics. Because of the increased interest in non-circular cross section plasma we will continue work in this area and explore in the near future the effect of these deformations on the classical diffusion, as well as the equilibria for currents with non-flat density profiles.

II. Mirror Confinement Studies

A) Finite beta Stabilization of Absolute Loss-Cone Instabilities.

The two-dimensional criterion for absolute instabilities (see R. Jong and T. Kammash, Nuclear Fusion 12, 5, 1972) is applied to mirror confined plasma without invoking the electrostatic approximation in order to assess the effect of finite beta on the stability of plasma in these devices. The equations of Callen and Guest (ORNL-TM 3671, 1972) have been extended to include density gradients thereby allowing the study of drift modes in open-ended systems. The effect of finite beta on a number of well known and important Loss-Cone modes has been examined and the results will be detailed in a paper to be submitted for the upcoming IAEA meeting in Tokyo. The following is a brief summary of the important results:

- i) The Dory-Guest-Harris mode appears to be amenable to finite beta stabilization in that the transition density as expressed in W_p^2 / W_c^2 of the ions increases from 17 at beta of zero to about 307 at beta of 0.46. The transition density is taken to be that which corresponds to the transition from a convective to an absolute mode.
- ii) Loss-Cone modes as characterized by a ($j=1$) ion distribution function and a Maxwellian electron distribution also appear to stabilize with finite beta. The results show that the transition density W_{pi}^2 / W_{ci}^2 increases from 0.9 to 4.00 for an increase in beta from zero to 0.6. Stabilization is further illustrated in this case by the fact that the plasma need not be as short and stubby as in the case of the pure electrostatic approximation.

iii) The Drift-Cone instabilities were examined as a result of the density gradient terms in the coupling between electrostatic and electromagnetic oscillations. Finite beta has a stabilizing effect on these modes but to a lesser extent than in the case of the Loss-Cone modes in homogeneous plasma given above. For the same range in β , the transition density goes from 0.67 to 2.68 instead of 4 as in the previous case.

As a continuation of this effort we plan to investigate other modes e.g. the drift cyclotron instability, and to assess the effects of collision through the use of the B.G.K. model.

B) Feedback Stabilization of Mirror Instabilities.

The effort in this area thus far has concentrated on calculating the frequency of a feedback system necessary to stabilize Loss-Cone Modes in a collisionless, inhomogeneous plasma. The system is simulated by adding a feedback source term in the Vlasov equation and we have shown so far that flute-like drift cyclotron and drift cone modes can be stabilized by this method. This stabilization can be accomplished with 90° phase shift at low and high plasma densities.

Because of relevance to current mirror experiments we plan to extend this investigation to open-ended systems with collisional distributions taking into account finite geometry effects.

II. Reactor-Related Studies

A) Thermal Stability of Tokamak Reactors with Impurity and Neutral Injection.

Previous investigations (see Horton & Kammash, Nuclear Fusion 13, 753, 1973) of thermal equilibrium states have shown that a Tokamak type fusion reactor subject to either drift wave or trapped particle anomalous diffusion is capable of thermally stable operation without external controls.

The dynamic equations of the above reference have been modified to allow for an additional non-reacting (impurity) species as well as for fuel injection at an arbitrary initial energy to simulate neutral injection heating. As in the previous study, no equilibrium state can be found in the case of neoclassical confinement for which energy and particle confinement times are different. In the case of drift wave diffusion which seems to be most desirable from the point of view of thermal stability it is shown that an increase in the impurity level causes the system to become less stable, the ion density at equilibrium to rise somewhat and the temperature of the various plasma components to drop. The result is usually that a somewhat larger torus is required to produce a given power level. However for the larger (higher power) reactors this result usually reverses and a high impurity level may enable a given torus to produce more power though with less inherent stability. As for the use of neutral beam injection for heating we find that a quite spectacular improvement in stability is possible for reactors of 1000 megawatts or less by injecting the ions between 10 and 50 kev. For reactors with a total power of 3000 megawatts or more (for beta of 0.10), energetic injection of ions actually reduces the stability slightly and it appears that use of an injection energy greater than 50 kev would degrade the stability somewhat relevant to the 50 kev case except at extremely small power levels. Unfortunately, the improvement in stability, where present, occurs only when the injected power is an appreciable fraction of the fusion power. Thus, energetic ion injection is likely to improve stability only at a considerable cost in overall efficiency. These results are summarized in a paper scheduled for presentation at the topical conference on the technology of controlled fusion in San Diego April 15, 1974.

B) Charged Particle Heating of Turbulent Plasma.

This investigation has just been started to estimate the effect of turbulence on the energy exchange between an incident charged particle and a target plasma. The slowing down process in the absence of collective effects has been studied in detail for both heavy charged particles (Kammash and Galbraith, Nuclear Fusion 13, 133, 1973) and relativistic electrons (Kammash and Galbraith, 13, 464, 1973) and in the presence of stable oscillations using the Leonard-Balescu equations by Sigmar and Joyce (Nuclear Fusion 11, 447, 1971). Of special importance to plasma heating by neutral injection is the understanding of the energy exchange process in the presence of instabilities which the incident beam might trigger. The Balescu-Leonard equations are inadequate since they do not allow for unstable roots of the plasma dielectric and a theory which allows for that must be used. Presently the theory of Ichimaru and Rosenbluth (Physics Fluids 13, 2778, 1970) is being examined for application in this problem.

CONFERENCE PAPERS AND PUBLICATIONS

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