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ANNUAL REPORT

TITLE: Anomalous Transport in Toroidal Plasmas

PRINCIPAL INVESTIGATOR: Dr. Alkesh Punjabi

REF.: DE-FG05-88ER53265

SUBMITTED TO: Dr. Walter Sadowski
US DoE
ER 541
Room G240
Washington D.C. 20545

INSTITUTION: Hampton University
Hampton VA 23668

W. R. Harvey

William R. Harvey
PRESIDENT

CONTENTS

This is annual progress report for the research project "Anomalous transport in toroidal plasmas" funded by DoE under the grant DE-FG05-88ER53265. The PI for this project is Dr. Alkesh Punjabi. This report covers the period June 1 1990 to May 31 1991. This report also includes the budget for the period June 1 1991 to May 31 1992.

I. THESES COMPLETIONS:

In April 1990, Ms. Kathy Burke completed her requirements for M.S. in applied mathematics from Hampton University. She successfully defended her thesis titled "A Monte Carlo method for transport in Reversed Field Pinch". Ms. Burke was supported by this grant. She is an afro-american female. After the completion of her degree at HU, she started working for a private corporation. Presently she engaged in computational work on supercomputers for DoD contracts. Her training in this research project helped her significantly in getting this position and training her for the present employment.

Another graduate student, Ms. Muyng-Hee Kim, completed her requirements for M.S. degree in applied mathematics in Spring 1991. The title of her thesis is "Electron transport in the stochastic fields of RFP ZT40". She was supported by this grant. Ms. Kim is a Korean female. She has been accepted for PhD program in applied science program at College of William and Mary. She is also receiving graduate research assistantship. Her training and preparation in this research project played a key role in her successes.

Starting from Fall 1990, a new minority graduate student is supported by this grant.

II. PUBLICATIONS:

One manuscript was submitted to Journal of Plasma Physics and it has been accepted for publication. This paper will be 26 journal pages long. The authors include the graduate students Ms. Muyng-Hee Kim and Ms. Kathy Burke. The expected date of publication is in the first half of 1991. A copy of preprint of this paper is enclosed. The title and authors are:

Monte Carlo calculations for transport due to MHD modes
A. Punjabi, A. Boozer, M. Lam, M. Kim and K. Burke
Accepted for publication in Journal of Plasma Physics

Another manuscript is submitted to XXth International Conference on Phenomena in Ionized Gases to be held in Italy in July 1991. This manuscript will be refereed by the international scientific committee. The title and authors are:

Electron transport in the stochastic fields of RFP ZT40M
A. Punjabi, A. Verma, M. Kim and A. Boozer
Submitted to XXth ICPIG 1991

III. CONTRIBUTED PAPERS:

The following contributed papers were presented:

Monte Carlo calculations for transport due to MHD modes
A. Punjabi, M. Kim and A. Boozer
1990 APS DPP meeting
Bull. Am. Phys. Soc., 35, 2139 (1990)

Anomalous transport in toroidal plasmas
A. Punjabi, A. Boozer, K. Burke and M. Kim
Sherwood meeting, paper 1C5, 1990

Following paper will be presented at 1991 Sherwood meeting:

Stochastic broadening in the divertor region using standard map
A. Punjabi, A. Verma and A. Boozer

The abstracts of these papers are enclosed. Ms. M. Kim will present the results of her MS thesis work at the 1991 VAS annual meeting in May 1991.

IV. RESEARCH:

The transformation to non-canonical, rectangular co-ordinates for the drift particle trajectories was completed. This is a non-canonical transformation from the non-canonical, practical co-ordinates to the non-canonical, rectangular co-ordinates[1-3]

$$(v_\parallel, \chi, \theta, \phi, E) \rightarrow (v_\parallel, x, y, \phi, E)$$

where

$$x=\sqrt{\chi}\cos(2\pi\theta)$$

and

$$y=\sqrt{\chi}\sin(2\pi\theta).$$

Rectangular co-ordinates are required to integrate the drift orbits when particles are too close to or go through the magnetic axis. By making transformation to rectangular co-ordinates, we circumvent the difficulties associated with singularities at the magnetic axis. A typical θ-t plot is shown in figure 1. This figure shows the trajectory of a passing electron in RFP. The initial conditions are $r_0=10^{-9}, \theta_0=0, \phi_0=0$ [3]. These transformations have been incorporated in the codes RFPCH and TKMKCH[1-3] which calculate the drift trajectories and transport coefficients in the RFP and tokamak. After that, these codes have been debugged and tested. Calculations for similar transformation for field line trajectories[1,3] have been completed. However, they are yet to be incorporated in the codes FIELD and TF for RFP and tokamak respectively.

From Bessel function model of RFP [1], we show that

$$B(r)=\sqrt{J_0^2(kr)+J_1^2(kr)}.$$

We use least square method to approximate this in χ space by

$$B(\chi)=1-c\chi$$

where c is a constant which equals 0.1111 [2,3]. This expression includes the effects of radial gradient in the field strength. The toroidicity effects are included by adding the term $-\epsilon_a\chi^{1/2}\cos(2\pi\theta)$ to the above expression for magnetic field strength. The resulting expression for B is incorporated in the code RFPCH [2,3]. Then the code has been debugged and tested.

For the resistive perturbations, we now use the spectrum [2,3]

$$\psi(\chi,\theta,\phi)=\psi_0(\chi)+a\sum_n f(\chi)\cos(\theta-n\phi+\delta_n)$$

where ψ_0 is the unperturbed toroidal flux and the second term represents the resistive perturbations. The function $f(\chi)$ is given by

$$f(\chi)=\frac{1}{n}\left(\frac{\chi}{\chi_n}\right)^{3/2} \qquad when\ \chi\le\chi_n$$

and

$$f(\chi)=\frac{1}{n}\left(\frac{\chi_n}{\chi}\right)^{3/2} \qquad when\ \chi>\chi_n.$$

Here χ_n is the χ co-ordinate of the resonant surface with m=1 and toroidal mode number n. The codes RFPCH and FIELD have been modified to use the above representation for the resistive perturbations, and the modified code has been debugged and tested. The χ_n's are obtained by linear interpolation and binary search [3]. The difference between this spectrum and the previous one [1] is that the new spectrum does not cause wobbling of magnetic surfaces [1,2]. We choose a large number of toroidal modes with m=1 in RFP ZT40M and calculate the diffusion coefficient $D_N(E,r)$ given by

$$D_N(E,r)=\sum_{j=1}^{j=64}\frac{(\Delta r_j)^2}{2N\,\tau_{collision}},\qquad N = \text{a positive integer}.$$

We fix energy E of the electrons at 225 eV. Initial conditions are: $r_0=1/2$, θ_0, ϕ_0 and the pitch λ_0 are chosen randomly. $\tau_{collision}$ is the collision time for density $n=10^{13}$ cm^{-3}, temperature T=150 eV, magnetic field B=5 KGuass. We calculate the asymptotic value D(E,r) in the limit of N becoming large [2]. The preliminary results are shown in figure 2. D(E,r) shows the Rechester-Rosenbluth scaling [4]. D(E,r) oscillates about the Rechester-Rosenbluth value. We are continuing this study and final results will be presented at ICPIG in July [2]. The resulting break-up of the magnetic surfaces is also being studied using the code FIELD [2].

A new method is now being developed to calculate χ_n analytically. This is done by solving

$$\frac{d\chi}{d\psi_0(\chi)}=n$$

with

$$\psi(\chi_0)=\sum_{i=1}^{i=4}C_i\chi^i.$$

C_i are constants and their values are given in ref. 1. This new method will be adopted in the codes RFPCH and FIELD.

Another problem that we are studying is that of estimating the energy confinement time τ_E as a function of the edge safety factor q_{edge} for the tokamak Topkapole II. Based on the experimental evidence [5,6], we have constructed new spectrum of magnetic perturbations which more closely corresponds to the tokapole II experiment. New spectrum differs from the old one [1] when $q_{edge}\leq 1$ and $r>r_{mn}$ such that

$$B_r \propto (1-r+r_{mn}).$$

This will result in the change in the values of $C(q_{edge})$ which is equivalent of stochasticity parameter [7]. At present we are modifying the code CQEDGE to obtain the new values for parameter $C(q_{edge})$. Later the new spectrum for B_r will be incorporated in the codes TKMKCH and TF.

V. FUTURE PLANS:

Our plans for the research in the period June 91 to May 92 will concentrate on two problems.

The first one will be to use the new spectrum for the magnetic perturbations in tokapole II in particle drift trajectory code TKMKCH to calculate τ^E as function of q_{edge} for tokapole II. Results will be compared with the experiment [5]. The same spectrum will also be used in tokamak field line trajectory code TF to obtain the field portraits in tokapole II.

The second problem concerns the understanding of anomalously high edge electron current in RFP ZT40M [8]. To study this problem we will use a slight modification of the new spectrum of resistive perturbations in RFP discussed above. In this modified form $f(\chi) \propto (\chi_n/\chi)^{1/2}$ outside the resonant surface with mode numbers (m=1,n). The improvements indicated above-the expression for $B(\chi)$ with radial gradients and toroidicity, and analytic calculations for resonant surfaces χ_n-will be adopted in the codes RFPCH and FIELD. Then the code RFPCH will be used to evaluate the trajectory of electrons which start out in the core of RFP ZT40. Loop voltage and resistive perturbations will be turned on. We will attempt to study relaxation of Maxwellian distribution of these electrons. From this we will attempt to determine electron current in edge region. The results may then be compared with experiment. The code FIELD will also be used in conjunction with the code RFPCH to calculate field portraits in which electron drift trajectories are evaluated.

We will continue our efforts to expand the base of nuclear fusion research and training of graduate and undergraduate students at our HBCU. We will submit the results of our research papers to professional journals for publication. Results will also be presented at conferences like Sherwood and APS DPP.

VII. REFERENCES:

[1] Punjabi A., Boozer A., Lam M., Kim M. and Burke K.
To appear in the J. Plasma Phys.

[2] Electron transport in the stochastic fields of RFP ZT40M
Punjabi A., Verma A., Kim M. and Boozer A.
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[3] Kim M., MS thesis applied mathematics, Hampton University (1991)

[4] Rechester A.B. and Rosenbluth M.N., Phys. Rev. Lett., **40**, 38 (1978)

[5] Graessle D.E., Prager S.C. and Dexeter R.N., Phys. Rev. Lett., **62**, 535 (1989)

[6] Graessle D.E., PhD thesis in physics, Univ. of Wis. Madison (1989)

[7] Chirikov V., Phys. Rep., **52**, 263 (1979)

[8] Ingraham J.C., Ellis R.F., Downing J.N., Munson C.P., Weber P.G. and Wurden G.A., Phys. Fluids B, **2**, 143 (1990)

VIII. FIGURES

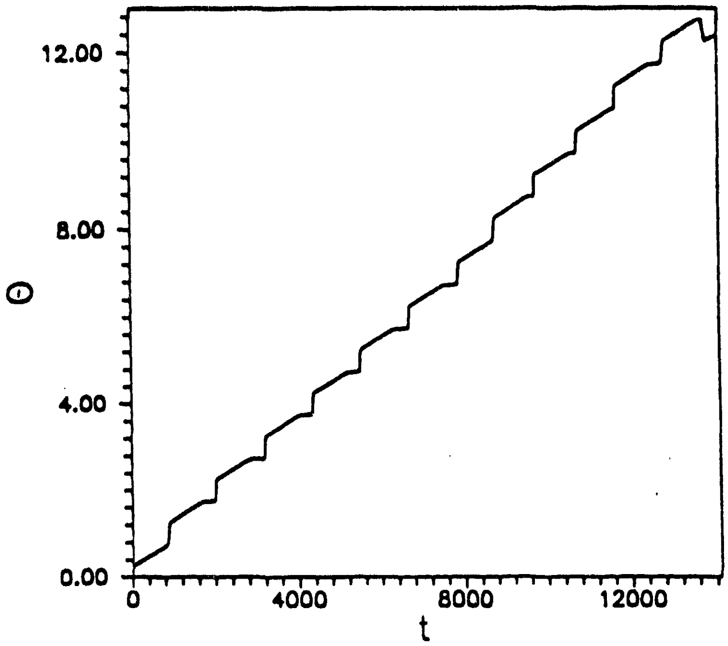

Figure 1

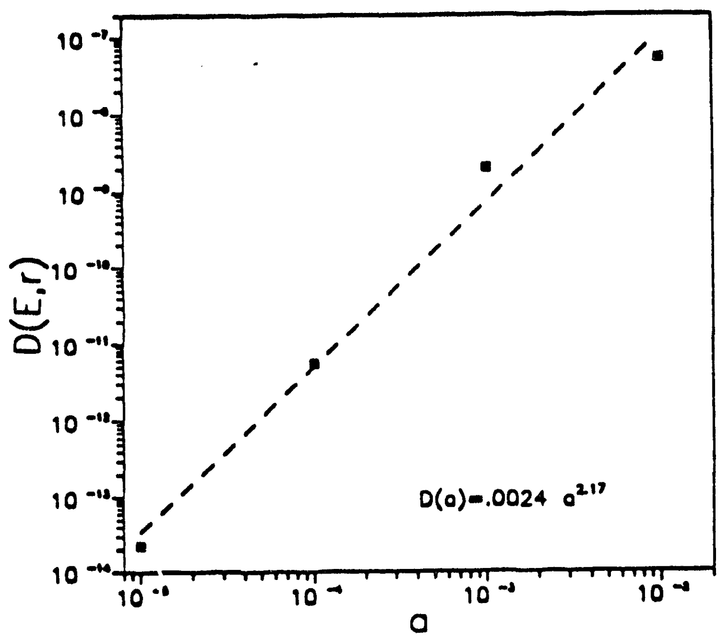

Figure 2

ANOMALOUS TRANSPORT IN TOROIDAL PLASMAS

Alkesh Punjabi
Hampton University
Hampton VA 23668

Allen Boozer
College of William & Mary
Williamsburg VA 23185

Kathy Burke and Kim Muytung
Hampton University
Hampton VA 23668

We have developed a Monte Carlo method to estimate the transport of different groups of particles for plasmas in toroidal geometries. This method can determine the important transport mechanisms driving the anomalous transport by comparing the numerical results with the experimental data. The important groups of particles whose transport can be estimated by this method include runaway electrons, thermal electrons, both passing and trapped diagnostic beam ions etc. The three basic mechanisms driving the anomalous transport are: spatial variation of magnetic field strength, spatial variation of electrostatic potential within the flux surfaces, and the loss of flux surfaces. The equation of motion are obtained from the drift hamiltonian. The equations of motion are developed in the canonical and in the non-canonical, practical co-ordinates as well. The effects of collisions are represented by appropriate stochastic changes in the constants of motion at each time-step. Here we present the results of application of this method to three cases: superathermal alphas in the rippled field of tokamaks, motion in the magnetic turbulence of tokapole II, and transport in the stochastic fields of ZT40.
This work is supported by DOE OFE and ORAU HBCU program.