DOE/ER/53285-1

DOE/ER/53285--1

DE92 008426

COMPUTATIONAL METHODS FOR STELLERATOR CONFIGURATIONS

PROGRESS REPORT

For the Period May 15, 1989 - December 31, 1989

Prepared for

THE U. S. DEPARTMENT OF ENERGY
DE-FG02-89ER53285

Prepared by:
Professor Octobio Betancourt
Principal Investigator
Department of Computer Science
The City College of CUNY
Convent Avenue @ 138th Street
New York, NY 10031

Progress Report

"Computational Methods for Stellarator Configurations"
Grant **DE-FG02-89ER53285**

This project consists of two parallel objectives. On the one hand, computational techniques for three dimensional magnetic confinement configurations were developed or refined and on the other hand, this new techniques were applied to the solution of practical fusion energy problems or the techniques themselves were transferred to other fusion researchers for practical use in the field.

The former objective consists on further development of the 3D spectral code **BETAS**. The first improvement was the development and implementation of a free boundary algorithm, which included enhanced resolution over previous finite difference versions, a fast iterative solver for the vacuum region and a modification to the variational principle to allow for computation of free boundary equilibria with non-zero net currents as in the Tokamak case. This work was reported in [1] (see attached pre-print).

A further extension and improvement of this code was the implementation of a general coordinate system for the plasma region, resulting in improved convergence near the magnetic axis, as well as allowing for calculation of more general classes of highly distorted equilibrium configurations. This work was reported at the last APS meeting in Los Angeles (see attached abstract).

The second part of this project consists on collaboration efforts with other fusion researchers. I visited ORNL during the summer to work with S. Hirshman. Our aim was to implement in his 3D spectral code **VMEC** a version of a fast iterative algorithm which I developed for the **BETAS** code. This was a strong success and it resulted in a new version of Hirshman's code which we called **SPEC**, Spectral Preconditioned Equilibrium Code. This new version converges up to six times faster than the previous one for finer meshes and it converges well in free boundary cases for which the previous version did not succeed. This represents a very significant savings of large amounts of computer time as well as an extension of the range of applications for this code.

In addition, I visited Princeton and established the basis for collaboration with J. Johnson on a version of his averaging techniques for stability calculations of numerically computed Stellarator Equilibria. In the near future I will start work with J. Talmadge of the Wisconsin Torsatron laboratory on Monte Carlo simulation of the effects of Electric Fields on particle transport in

Torsatrons, with the aim of explaining some of his experimental observations.

Publications :

1.- O. Betancourt, " A Free Boundary Algorithm for the BETAS code", to appear in the Proc. of the VII international workshop on Stellarators, Oak Ridge, April 1989. *

2.- S. Hirshman and O. Betancourt, " Preconditioned Descent Algorithm for Rapid Calculations of Magnetohydrodynamic Equilibria", submitted to Journal of Comp. Physics. *

Meetings :

1.- O. Betancourt, " The **BETAS** code : Further Development and Applications", APS meeting, Los Angeles, Oct. 1989.

2.- S.Hirshman and O. Betancourt, " **SPEC** : Spectral Preconditioned Equilibrium Code ", APS meeting, Los Angeles, Oct. 1989.

* removed and cycled separately -

GUEST ASSIGNMENT OF OCTAVIO BETANCOURT TO FUSION ENERGY DIVISION

(June 26 - June 30, 1989)

Octavio Betancourt, Professor of Computer Science, City College, CUNY, arrived at Oak Ridge National Laboratory on June 26, 1989, and departed on June 30, 1989.

This assignment primarily involved interactions with members of the Fusion Energy Division Theory Section, with S. P. Hirshman and J. A. Rome acting as hosts and escorts. The assignment involved collaborative work with S. P. Hirshman, and discussions with J. A. Rome, L. Hively, and N. Dominguez.

During this assignment, Prof. Betancourt provided technical guidance to S. P. Hirshman in the field of mathematical physics. In particular, a preconditioning algorithm was developed for improving the convergence rate of the three-dimensional equilibrium code VMEC. At the end of this visit, the basic feasibility of the algorithm was demonstrated on two-dimensional test cases, with factors of three improvement in convergence already observed. Provided this early result continues to apply in the three-dimensional cases, this work constitutes a major advance in the VMEC code.

Dr. Betancourt provided S. P. Hirshman with a copy of his technical article in Comm. Pure and Applied Mathematics, Vol. XLI, 551 (1988). This assignment led to an abstract for the APS fall meeting, and it is hoped that a paper will be shortly forthcoming. Further collaboration concerning free boundary equilibria, which was only initiated during this visit, is possible in the future.

Submitted by: Steven P. Hirshman Date: 6/20/89

Steven Paul Hirshman
Fusion Energy Division

3Q 25 **SPEC : Spectral Preconditioned Equilibrium Code.***

S. P. Hirshman and O. Betancourt + ORNL.

The MHD spectral code VMEC [1] was developped to analyze finite equilibria in three dimensional toroidal configurations. Previously, an iterative conjugate gradient descent method was used to minimize the MHD Energy and locate local stable equilibria. Numerical studies with VMEC have shown that the number of iterations required for convergence grows linearly with the number of radial mesh points.

This undesirable dependence on the radial mesh can be ameliorated by using a preconditioning matrix (PM) to coalesce the eigenvalues around unity. An invertible triadiagonal PM is derived for the force balance equations used in VMEC.

The temporal convergence of the resulting SPEC code is compared with that of VMEC for several realistic 3-D equilibria. It is shown that only a weak dependence of the convergence rate on the radial mesh remains in SPEC after preconditioning, with preliminary results showing speed up by a factor of 3 already on crude meshes.

* Research sponsored by the office of FUSION Energy, U. S. Department of Energy, under Contract No. DE-AC05-84OR21400

with Martin Marietta Energy Systems Inc., and USDOE contract No. DE-FG02-89ER53285.

+ City College, CUNY.

1 S. P. Hirshman, U. Schwenn, J. Nuhrenberg, to be published in J. Comp. Physics. (1989).

2 O. Betancourt, Comm. Pure and Applied Math. XLI, 551. (1988).

3Q15 **The BETAS Code** : Further Developpment and Applications.*

O. Betancourt, City College, CUNY.

The 3D spectral code BETAS was described in [1], with applications to non-linear stability and island formation problems. A free boundary algorithm was reported in [2].

We have now implemented a more general coordinate system, which allows equilibrium calculations in non star-like domains and improves convergence near the axis.

We will also report on an application of the free boundary version to a non axisymmetric model for the ITER Tokamak with a small number of toroidal field coils.

* Research supported by the U. S. Department of Energy under grant DE-FG02-89ER53285.

1 O. Betancourt, Comm. Pure and Appl. Math., XLI, 551 (1988).

2 O. Betancourt, Proc. VII International Stellarator Workshop (to appear).

END

DATE
FILMED
3/24/92