Experimental Studies of Magnetic Islands, Configurations and Plasma Confinement in the H-1NF Heliac

A thesis submitted for the degree of
Doctor of Philosophy of
The Australian National University

by

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This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge and belief, it contains no material previously published or written by any other person, except where due reference is made in the text.

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"The difference between what we do and what we are capable of doing would suffice to solve most of the world's problems."

Mahatma Gandhi

Dedicated to my parents

Contributions

The majority of experimental results presented in this thesis have been obtained by the author, entirely during the course of this project, in cooperation with Boyd Blackwell. I draw special attention to the following contributions.

- The image warping technique (mentioned in chapter 3) and the method of calculation of ι near a rational surface (appendix C.1) are developed by Boyd Blackwell for this project.
- The fast mapping system is developed by Mark Gwynneth, with the guidance of Boyd Blackwell, as a part of an engineering project.
- Figure 4.21 and the details about the Mirnov fluctuation experiments are provided courtesy of David Pretty.
- The spectroscopic results have been obtained in cooperation with John Howard.

Much of the experiments, data analysis, interpretation and theory have been done by the author, with guidance from Boyd Blackwell. Technical contributions are acknowledged in the acknowledgement section. Any other contributions are acknowledged in the usual fashion of referencing.

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Abstract

Rational magnetic flux surfaces in fusion (toroidal plasma confinement) devices can break the magnetic field lines and reconnect them in the form of magnetic islands. Formation of these magnetic islands can have a serious impact on the plasma confinement properties of the device. Islands can in general degrade the confinement by mixing up different regions of the plasma. However there has been experimental evidence of confinement improvement by island induced transport barriers, under certain conditions. Even though there are a large number of theoretical and experimental works on magnetic islands to date, there is clearly a paucity of convincing experimental understanding on the nature of behaviour of islands in plasma. This thesis reports detailed experimental studies conducted on the H-1NF heliac stellarator, to gain an in-depth understanding of magnetic islands and their influence in plasma confinement.

Work reported in this thesis can be mainly divided into three parts: (a) high resolution imaging of vacuum magnetic islands and flux surfaces of H-1NF, (b) accurate computer modeling of H-1NF magnetic geometry and (c) detailed experiments on magnetic islands in plasma configurations.

Electron-beam wire-tomography in the H-1NF has been used for the high resolution mapping of vacuum magnetic flux surfaces and islands. Point-to-point comparison of the mapping results with computer tracing, in conjunction with an image warping technique, has enabled systematic exploration of magnetic islands and surfaces of interest. A fast mapping technique has been developed, which significantly reduced the mapping time and made this technique suitable for mapping at higher magnetic fields.

Flux surface mapping has been carried out at various magnetic configurations and field strengths. The extreme accuracy of this technique has been exploited to understand the nature of error fields, by point-by-point matching with computer tracing results. This has helped in developing a best-fit computer model for H-1NF magnetic configurations, which can predict rotational transform correct to three decimal places. Results from plasma experiments on magnetic configuration studies are best explained by the new model.

Experiments with low order magnetic islands in plasma configurations yielded some new results. It has been observed that the low order magnetic islands ($m = 2$) near the core of the plasma serve as 'pockets' of improved confinement region under favourable conditions. This results in significant profile modifications including enhancement of the radial electric field near the core to a large positive value. The characteristics of islands are found to be dependent on the plasma collisionality and the island width.

Experiments with a magnetic configuration which exhibits no vacuum islands, but the core rotational transform (ι) very close to low order rational value, show a spontaneous transition of the radial electric field near the core to a large positive value ($E_r \sim 5$ kV/m), with a strong electric field shear (~ 700 kV/m^2) and localised improvement in confinement, during the discharge. Evidence indicates that the transition is driven by the excitation of low order ($\iota = 3/2$) magnetic islands near the axis during the plasma discharge, due to the modification of rotational transform profile by toroidal plasma currents. The situation is similar to the Core Electron-Root Confinement (CERC) observed during high temperature ECH plasma discharges on other helical devices. This result provides an experimental evidence for the hypothesis that the threshold conditions for observing CERC can be reduced by exciting magnetic islands near the core of the plasma.

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