

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

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 t 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 (t) 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/m²) and localised improvement in confinement, during the discharge. Evidence indicates that the transition is driven by the excitation of low order ($t = 3/2$) 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.

Contents

| | | |
|----------|---|-----------|
| 1 | Introduction | 1 |
| 1.1 | Energy, fusion and plasma physics | 1 |
| 1.2 | Magnetic confinement geometries | 5 |
| 1.3 | Magnetic properties of fusion devices | 8 |
| 1.4 | Magnetic islands | 10 |
| 1.4.1 | Formation of islands | 12 |
| 1.4.2 | Impact of islands on plasma confinement | 13 |
| 1.5 | Objectives of this study | 15 |
| 1.6 | Thesis organisation | 17 |
| | | |
| 2 | The H-1 Helic | 19 |
| 2.1 | Machine overview | 19 |
| 2.1.1 | The coil system | 19 |
| 2.1.2 | Plasma production and heating | 23 |
| 2.1.3 | Diagnostics | 24 |
| 2.2 | Magnetic properties of H-1NF | 25 |
| 2.2.1 | Rotational transform, magnetic shear and well | 25 |
| 2.2.2 | Fourier spectrum of magnetic field | 27 |
| 2.2.3 | Magnetic islands in H-1NF | 28 |
| | | |
| 3 | Mapping of vacuum magnetic islands and surfaces | 32 |
| 3.1 | Introduction | 32 |
| 3.2 | Experimental setup | 33 |
| 3.3 | Mapping and reconstruction | 36 |

| | | |
|----------|---|------------|
| 3.3.1 | Sinogram | 36 |
| 3.3.2 | Simple back-projection | 37 |
| 3.3.3 | Algebraic Reconstruction Technique (ART) | 40 |
| 3.4 | Image warping technique | 40 |
| 3.5 | Fast mapping | 43 |
| 3.6 | Critical issues | 45 |
| 4 | Accurate determination of H-1NF magnetic geometry | 47 |
| 4.1 | Introduction | 47 |
| 4.2 | Experiment | 48 |
| 4.3 | Error estimation and computer modeling | 50 |
| 4.3.1 | Stage I: $\kappa_h = 0$ | 59 |
| 4.3.2 | Stage II: The helical winding | 61 |
| 4.3.3 | Stage III: Magnetic islands | 63 |
| 4.4 | Modified magnetic properties of H-1NF | 67 |
| 4.5 | Mapping at higher magnetic fields | 68 |
| 4.6 | Verification from plasma experiments: Mirnov fluctuations | 71 |
| 5 | Islands in plasma configurations | 75 |
| 5.1 | Introduction | 75 |
| 5.2 | Experimental setup | 76 |
| 5.3 | Experimental results | 79 |
| 5.4 | Results from spectroscopy | 83 |
| 5.5 | Discussion | 84 |
| 5.6 | Islands at the edge | 91 |
| 6 | Spontaneous bifurcation of the radial electric field | 95 |
| 6.1 | Introduction | 95 |
| 6.2 | Experiment | 96 |
| 6.3 | Results and discussion | 97 |
| 7 | Conclusions and future scope of study | 106 |

| | |
|---|-----|
| CONTENTS | xii |
| Appendices | 110 |
| A Flux coordinates | 110 |
| B The <i>HELIAC</i> code input file and TFC locations | 112 |
| C Calculation of t near a rational surface | 117 |
| D Langmuir probe | 120 |
| Bibliography | 126 |

List of Figures

| | | |
|-----|---|----|
| 1.1 | Cross sections for a few fusion reactions | 4 |
| 1.2 | Schematic of a mirror device | 6 |
| 1.3 | Schematic of a tokamak (Figure courtesy http://www.ipp.mpg.de) . . | 7 |
| 1.4 | Schematic of stellarator. (a) W7-X stellarator being built in Germany (Figure courtesy http://www.ipp.mpg.de). (b) H-1NF heliac stellarator in The Australian National University | 7 |
| 1.5 | Magnetic flux surfaces of H-1NF heliac stellarator | 8 |
| 1.6 | Figure explaining the concept of rotational transform. One computed flux surface of H-1NF heliac is shown. Assume that 0 is the starting point of the field line and 1 is the position of the field line after first toroidal transit. In actual case of H-1NF, the angle ι is more than 2π | 9 |
| 1.7 | Magnetic flux surfaces of H-1NF heliac (computed using the <i>HELIAC</i> code) showing configurations exhibiting (a) $m = 2$ islands and (b) $m = 5$ islands | 11 |
| 1.8 | Top view of the magnetic island structure ('snake' in blue colour) of H-1NF heliac (computed using the <i>BLINE</i> code). (a) $m = 2$ islands and (b) $m = 5$ islands. Vertical (i) and toroidal (ii) field coils are marked. | 11 |
| 1.9 | Formation of magnetic islands. (a) Radial component of the perturbation. (b) Poloidal magnetic field ($B^* = B_0 - B_{mn}$) showing the magnetic shear. (c) Magnetic island | 12 |

| | | |
|-----|---|----|
| 2.1 | Coil structure of H-1NF showing the ring conductor(1), the toroidal field coils (2), the helical winding (3), the outer vertical field coils (4) and the inner vertical field coils(5). (Figure courtesy John Wach) | 20 |
| 2.2 | Rotational transform profiles and computed flux surfaces (at $\phi = 85^\circ$) for three different magnetic configurations of H-1NF: the ‘full helical’ ($\kappa_h = \kappa_v = 1.0$), ‘half vertical’ ($\kappa_h = 0.0$, $\kappa_v = 0.5$) and the ‘standard’ ($\kappa_h = 0.0$, $\kappa_v = 1.0$) configurations. | 22 |
| 2.3 | Plan view of the H-1NF coil structure showing the outer vertical field coils(i), vacuum tank(ii), toroidal field coils(iii), ring conductor(iv), helical winding(v), inner vertical field coils(vi) and the locations of various diagnostics and heating system. 1. Langmuir probe & Rogowski coil 2. Electron gun 3. Mirnov coil arrays 4. Multi-wire collector 5. RF antenna 6. Fast-ion camera 7. Microwave interferometer 8. Coherence imaging camera (Figure courtesy John Wach) | 24 |
| 2.4 | Radial profiles of rotational transform for various magnetic configurations of H-1NF. (different κ_h values, $\kappa_v = 1.0$). Major rational values are marked on the right axis. Magnetic flux surfaces for two configurations are also shown. | 26 |
| 2.5 | Magnetic well profiles for κ_h scan | 28 |
| 2.6 | Fourier components of magnetic field, $[B_{nm} = \text{FFT}(B)]$ for the ‘standard’ (at $\langle r \rangle = 0.118$ m, $t = 1.157$) and ‘full helical’ (at $\langle r \rangle = 0.130$ m, $t = 1.401$) configurations. Negative values reflect the left handed helicity in the H-1NF and n values are not normalised to the field period. (File name: ‘modelSTByoffmodb.spec’ & ‘modelFHByoffmodb.spec’). | 29 |
| 2.7 | Variation of $ B $ on a surface for the ‘standard’ and ‘full helical’ configurations. i & ii are magnetic mirrors formed by toroidal and helical ripples respectively, and iii is the ripple due to discrete toroidal field coils. | 29 |
| 2.8 | Evolution of the $m = 2$ magnetic islands as the values of κ_h and κ_v are increased. | 30 |

| | | |
|-----|--|----|
| 2.9 | Computed flux surfaces of the ‘standard’ configuration (a) with and (b) without current cross-overs. The $m = 6$ islands appear only when the winding cross-overs for the ring conductor are included in the model. | 31 |
| 3.1 | Electron gun. The shield diameter at the aperture, $a=2.9$ mm, the projection beyond the aperture (tip), $b=1.5$ mm (Figure courtesy John Wach) | 34 |
| 3.2 | Rotating multi-wire assembly in park position. (Figure courtesy John Wach) | 35 |
| 3.3 | Sinograms of flux surfaces for (a) ‘full helical’ configuration ($\kappa_h = \kappa_v = 1.0$) (b) configuration exhibiting $m=2$ islands ($\kappa_h=\kappa_v= 1.27$). Shown in inset of figure (a) is the current through the longest wire (wire number 0) as a function of wire rotation angle. | 38 |
| 3.4 | Simple back projections (a) & (b) of data shown in figure 3.3 | 39 |
| 3.5 | ART images (a) & (b) of data shown in figure 3.3. Width of the island lobe in (b) is ~ 8 mm | 41 |
| 3.6 | Computed flux surfaces of the $m=2$ islands at the wire ($\phi = 85^\circ$) and the gun ($\phi = 35.2^\circ$) cross sections. Note that warping is not just a rotation - the thinner island at 85° becomes the thicker island at 35.2° , and vice-versa. | 42 |
| 3.7 | Warping by the best-fit (i) and the simple (ii) models. (a) ‘Full helical’ configuration. (b) Configuration exhibiting $m=2$ islands. In practice, we use a much more accurate model than the ‘simple’ model, and images (i) and (ii) would be almost indistinguishable from each other. | 43 |
| 3.8 | Warped image of the $m=2$ islands. The original data at $\phi = 85^\circ$ are shown in Fig 3.5(b) | 44 |
| 3.9 | Simple back-projections of slow(a) and fast (b) mapping of a flux surface. The image is clipped to make the points more distinct. | 45 |

| | | |
|------|--|----|
| 3.10 | Figures showing the internal rotational transform (and the half connection length) of islands. (a) $m=2$ islands and (b) One of the $m=6$ island lobes | 46 |
| 4.1 | Super-imposition of experimental mapping results (blue) for the (a) ‘Standard’, (b) ‘Full helical’ & (c) ‘Half vertical’ configurations on the corresponding computed flux surfaces (black) from the basic model. For best reproduction, overlaid figures in this chapter have been created so that image pixels are aligned with vertical and horizontal. Consequently, although the coordinate system is consistent within the figure, there are small angle ($\sim 3^\circ$) and offset ($R \sim 5$ mm, $Z \sim 15$ mm) errors when compared with the other figures. | 51 |
| 4.2 | An example of variation of the axis displacement (ΔR and ΔZ) given in table 4.2, as a function of toroidal angle (ϕ). Plotted is the displacement of magnetic axis of the ‘standard’ configuration, for a stray error field of 0.1% each in $+B_y$ and $-B_y$ directions. | 54 |
| 4.3 | Effect of various error fields on the ‘standard’ configuration. Stray fields have the same amplitude as mentioned in table 4.2. Thick line represents positive and the thin line represents negative directions for the error field, except for (d) where thick and thin lines are (indistinguishable) flux surfaces with and without cross-overs. See table 4.2 for details. | 55 |
| 4.4 | Effect of various error fields on the ‘Full helical’ configuration. Error amplitudes have the same value as mentioned in table 4.2. Thick line represents positive and the thin line represents negative directions for the error field, except for (d). | 56 |
| 4.5 | Effect of various error fields on the ‘Half vertical’ configuration. Error amplitudes have the same value as mentioned in table 4.2. Thick line represents positive and the thin line represents negative directions for the error field, except for (d). | 57 |

| | | |
|------|--|----|
| 4.6 | Determination of magnetic axis (dashed lines) using Langmuir probe and electron beam. i- ‘standard’ configuration, ii-‘full helical’ configuration. Axis shift from ‘standard’ to ‘full helical’, $\Delta R = 21.5$ mm. | 59 |
| 4.7 | Mapped flux surface from the ‘standard’ configuration overlaid on the best-fit computer code result (‘+’ points) | 61 |
| 4.8 | Mapped flux surface from the ‘half vertical’ configuration overlaid on the best-fit computer code result (‘+’ points) | 62 |
| 4.9 | Mapped flux surface from the ‘full helical’ configuration overlaid on the best-fit computer code result (‘+’ points) | 64 |
| 4.10 | Effect of the helical winding parameters on the configuration exhibiting $m=2$ islands. ($\kappa_h = \kappa_v = 1.27$). I. $R_{hw} = 1.0080\text{m}$, $\rho_{hw} = 0.0900\text{m}$ II. $R_{hw} = 1.000\text{m}$, $\rho_{hw} = 0.0930\text{m}$ | 64 |
| 4.11 | Mapped flux surface from the configuration exhibiting $m=2$ islands ($\kappa_h = \kappa_v = 1.27$) overlaid on the best-fit computer code result (‘+’ points) | 65 |
| 4.12 | Effect of ring conductor offsets in X and Y directions on $m=1$ islands ($\kappa_h = -0.4$, $\kappa_v = 1.0$). (a) $\Delta X = 2\text{mm}$, $\Delta Y = 0$ mm (b) $\Delta X = -2$ mm, $\Delta Y = 0$ mm (c) $\Delta X = 0$ mm, $\Delta Y = 2$ mm (d) $\Delta X = 0$ mm, $\Delta Y = -2$ mm | 66 |
| 4.13 | (a) The best-fit model predictions for $\kappa_h = -0.4$ ($m=1$ island) and (b) Mapped island surface for this configuration (blue) overlaid on the best-fit model result (‘+’). The best-fit surface has been marked on figure(a). | 66 |
| 4.14 | Rotational transform profiles with the best-fit (‘*’), intermediate (‘o’) and the basic (‘+’) models | 69 |
| 4.15 | Magnetic well profiles with the new (‘*’), intermediate (‘o’) and the basic (‘+’) models | 69 |

| | | |
|------|---|----|
| 4.16 | Comparison of the three models for the three magnetic configurations. Red-the best-fit model, Green- the basic model, Blue- the intermediate model. (a) ‘Standard’ configuration (b) ‘Full helical’ configuration (c) ‘Half vertical’ configuration | 69 |
| 4.17 | Mapping results of full helical configuration at different magnetic fields (a) 1500A (b) 3000A (c) 4500A (d) 6500A | 71 |
| 4.18 | Rotation of surface with different vertical error fields (i) with a vertical error field of $\sim 0.85\%$ (ii) with a vertical error field of $\sim 0.25\%$ of B_0 | 72 |
| 4.19 | Rotational transform (t) of a flux surface as a function of the square of the coil current (I^2). (a) The ‘full helical’ configuration. (b) The ‘standard configuration’ | 72 |
| 4.20 | (a) Mapping result from the ‘full helical’ configuration for different coil current overlaid on model with ring conductor replaced by a helical winding (a) $I_{coil}=1500A$, $R_{helix}=1.000m$, the helical swing radius, $\rho = 0m$ (b) $I_{coil}=6500A$, $R_{helix}=1.000m$, $\rho =0.0005m$ | 73 |
| 4.21 | Frequency scaling of Mirnov fluctuations (a) with the basic model (b) with the best-fit (low magnetic field) model (c) with the high field (ring conductor replaced with a helical winding) model. The vertical line shows the resonant value of rotational transform. (Courtesy of David G. Pretty) | 74 |
| 5.1 | Computed flux surfaces of the three configurations used for study. δ is the width of the vacuum magnetic island. The islands (Case II & III) are toroidally connected, as explained in section 1.4 | 78 |
| 5.2 | Radial profiles of plasma density (n_e), electron temperature (T_e), plasma potential (ϕ_p) and radial electric field (E_r) for the no-island configuration (Case I) at ~ 20 ms into the discharge. | 80 |

- 5.3 Radial profiles of plasma density (n_e), electron temperature (T_e), plasma potential (ϕ_p) and electric field ($-\nabla\phi_p$) for the island configuration (Case II) at ~ 10 ms (+) , ~ 20 ms (*) and ~ 30 ms (Δ) into the discharge. δ is the width of the vacuum magnetic island. (Note that the radial coordinate axis is extended to negative values to explore symmetries. The electric field is plotted as if the coordinates were Cartesian, and therefore would be expected to have odd symmetry about $\rho = 0$. The asymmetry about $\rho = 0$ is discussed in section 5.5) 81
- 5.4 Radial profiles of plasma density (n_e), electron temperature (T_e), plasma potential (ϕ_p) and electric field ($-\nabla\phi_p$) for the ‘doublet’ configuration (Case III) at ~ 10 ms (+) , ~ 20 ms (*) and ~ 30 ms (Δ) into the discharge. δ is the width of the vacuum magnetic island. 82
- 5.5 Radial profiles of plasma density and plasma potential for the island configuration (Case II) at three different neutral pressures. (+ Normal neutral pressure [Sh#59335-59388], * double neutral pressure [Sh#59471-59501], \diamond half neutral pressure [Sh#59503-59532]) 83
- 5.6 Viewing chord positions for the 16 channel imaging camera, overlaid on the flux surfaces from the configuration exhibiting $m=2$ vacuum magnetic islands (Case II). Channel numbers (0-15) are shown. 85
- 5.7 The spectral light intensity (normalised to the maximum brightness) for a configuration exhibiting vacuum islands (Case II), showing the lower island lobe is ‘brighter’ throughout the discharge. δ is the approximate width of one of the vacuum island lobes (the lower island lobe in figure 5.6). Plotted on the right side is the normalised brightness (arbitrary units) at ~ 20 ms into the discharge, and the O-points are shown. 85
- 5.8 The radial electric field for the island configuration (Case II), calculated from the pressure gradient using a radially flat ion temperature of 60 eV (b) and 30 eV (c), over plotted on the measured E_r (a). 87

| | | |
|------|---|-----|
| 5.9 | Computed flux surfaces of the configuration exhibiting the 6/5 magnetic islands at the edge. δ is the width of vacuum magnetic island. . | 92 |
| 5.10 | Radial profiles of plasma parameters for configuration exhibiting vacuum islands (6/5) at the edge, at ~ 20 ms into the discharge. Scatter in density is due to fluctuation in the plasma as explained in the text. | 93 |
| 6.1 | Spatial and temporal evolution of the plasma potential (ϕ_p) for the $\kappa_h = \kappa_v = 1.12$ configuration, showing the bifurcation at ~ 20 ms into the discharge (Sh#59712-59773). | 98 |
| 6.2 | Radial profiles of plasma density (n_e), electron temperature (T_e), plasma potential (ϕ_p) and electric field ($-\nabla\phi_p$) at ~ 10 ms (+) and ~ 30 ms (*) into the discharge. (Note that the radial coordinate axis is extended to negative values to explore symmetries. The electric field is plotted as if the coordinates were Cartesian, and therefore would be expected to have odd symmetry about $\rho = 0$.) | 99 |
| 6.3 | Fluctuations in the floating potential (at $\rho \sim 0.5$) before (I) and after (II) the shear layer excitation. (a) Time series of the floating potential (b) Power spectrum at two time intervals | 100 |
| 6.4 | Spectral light intensity measured from a 16 channel imaging camera which shows a sudden transition nearly at 30 ms into the discharge. (see figure 5.6 for viewing chords). Plotted on the right side is the normalised brightness (arbitrary units) at ~ 10 ms (+) , ~ 35 ms (*) into the discharge | 101 |
| 6.5 | Computed flux surfaces (a) and radial profiles [at ~ 10 ms (i) and ~ 35 ms (ii) into the discharge] of plasma potential (b) and electric field (c) for configuration exhibiting vacuum magnetic islands (case II, chapter 5). δ shows the vacuum island width. | 102 |
| 6.6 | The Rogowski coil signal for the plasma discharge of figure 6.4, typical of discharges discussed in this chapter. | 103 |

| | | |
|-----|--|-----|
| 6.7 | Rotational transform profiles computed using the <i>HELIAC</i> code, with (*) and without (+) a toroidal current of ~ 5 A, through the magnetic axis. | 103 |
| 6.8 | Modification of the flux surfaces due to a toroidal plasma current of ~ 5 A through the magnetic axis, computed using the <i>HELIAC</i> code. (a) Unperturbed vacuum flux surfaces (b) Modified flux surfaces. . . . | 104 |
| C.1 | A mapped surface having $t \sim 7/5$. Successive transits are numbered in time sequence, taking the brightest one as the first transit (0). This is confirmed by introducing a large gas fill ($\sim 10^{-5}$ Torr) which attenuates all but the first few transits, and increases the contrast of the surviving transits. | 118 |
| D.1 | Schematic of the Langmuir probe design. (Although the assembly is a tight-fit, there may be small gaps between all four concentric components). | 121 |
| D.2 | Schematic of the probe circuit | 121 |
| D.3 | Typical probe bias voltage (V_b) and probe current (I_p) traces for H-1NF argon plasma | 122 |
| D.4 | Current-voltage (I-V) characteristics of a Langmuir probe. Data from H-1NF argon plasma. | 123 |
| D.5 | Typical temporal profiles of plasma parameters obtained from the Langmuir probe for a 40 ms argon discharge. The sheath thickness correction in this case is ~ 0.12 mm to 0.15 mm. | 125 |

List of Tables

| | | |
|-----|--|-----|
| 2.1 | Major machine parameters of the H-1NF | 21 |
| 4.1 | Mapped flux surfaces from each of the following configurations at various coil currents (magnetic fields) as tabulated below are used for the work reported in this chapter. | 49 |
| 4.2 | Effects of various possible error fields on the magnetic axis, for three configurations used for study. (Evaluated at toroidal angle, $\phi = 0^\circ$). Reference is the basic model for the corresponding configurations. Movement of less than 0.1 mm is omitted. | 53 |
| 4.3 | Computed values of the percentage change in the rotational transform $[(\delta t/t) \times 100]$ of a flux surface, for a constant surface area, due to various error fields. Reference is the basic model for the corresponding configurations. Stray fields and offsets have the same magnitude as mentioned in table 4.2. | 54 |
| 4.4 | Table showing the sensitivity of the rotational transform (t) to the helical winding parameters, for the ‘full helical’ configuration. Reference is the basic model for the same configuration. | 63 |
| 4.5 | Summary table showing the modifications in the new model in comparison with the previous models | 67 |
| 5.1 | Typical plasma parameters for the usual neutral pressure discharge. . | 86 |
| B.1 | As-built measurements of the TF coil locations | 116 |