1.1 Introduction

Continuous toroidal current drive by radio-frequency (RF) travelling waves is an important area of tokamak fusion research. A continuously operated tokamak fusion reactor is envisaged in order to overcome a number of serious technical difficulties such as mechanical and thermal fatigue, associated with the use of a large-scale conventional pulsed device. RF toroidal current drive is one of the main approaches which has been adopted in the search for a steady-state tokamak fusion reactor. A survey of current drive methods directed towards tokamak fusion is the subject of an extensive review article recently published by FISCH(1987).

RF current drive can be subdivided into two categories depending on whether the magnitude of the wave phase velocity is much larger or smaller than the electron thermal velocity. Schemes which fall into the first category (such as lower-hybrid current drive), involve resonant absorption of the injected wave by a subgroup of the electron population giving them a net drift velocity relative to the other plasma particles. For the particular scheme mentioned, the lower-hybrid waves interact with electrons in the high energy tail of the electron distribution. Other schemes in this category involve trapping and accelerating electrons with thermal velocities close to the phase velocity of the injected wave.

The $\langle \tilde{\jmath} \times \tilde{b} \rangle$ RF current drive technique studied in the present work falls into the second category, where the phase velocity of the externally imposed travelling wave is less than the electron thermal velocity. The travelling wave is produced by an external coil structure through which appropriately phased RF currents are passed. The basic method of $\langle \tilde{\jmath} \times \tilde{b} \rangle$ or non-linear Hall effect current drive is described in Section 1.2. A review of the $\langle \tilde{\jmath} \times \tilde{b} \rangle$ current drive technique is given in Section 1.3.

In this review of $\langle \tilde{\jmath} \times \tilde{b} \rangle$ RF current drive, particular emphasis is placed on the Rotamak device and associated rotating magnetic field (RMF) studies. The Rotamak is a compact torus device in which the toroidal current is generated and maintained by a rotating magnetic field, see JONES(1979); HUGRASS et.al.(1980). The Rotamak studies at Flinders University were used as a basis for initial investigations in the closely related Rythmac device by DUTCH AND MCCARTHY(1986a).

The Rythmac devices were constructed to investigate $\langle \tilde{\jmath} \times \tilde{b} \rangle$ current drive in conventional toroidal geometry. One aim of the Rythmac project was to determine whether this technique of current drive could have application in the problem of continuous current drive for tokamaks. Theoretical studies of '$m = 1$ double-helix' $\langle \tilde{\jmath} \times \tilde{b} \rangle$ current drive in the Rythmac device have drawn from and extended previous cylindrical RMF studies.

It is worth noting that the high power Line Generators which were used to supply the RF coil currents in the Rythmac devices were also previously used on high power, short duration Rotamak experiments desribed by DURANCE AND JONES(1986).

The scope of the work presented in this thesis will be outlined in Section 1.4.

1.2 Basic Mechanism of Non-linear Hall Effect $\langle \tilde{\jmath} \times \tilde{b} \rangle$ Current Drive

Two physical models have been developed for the Rotamak project to describe the nonlinear Hall effect technique for driving steady azimuthal electron currents in an infinitely long plasma cylinder. The models will be described briefly below. The simpler of these two models was adapted to describe the different geometry of our $\langle \tilde{\jmath} \times \tilde{b} \rangle$ current drive studies in conventional toroidal plasma vessels. A large aspect ratio cylindrical approximation was used to retain simplicity.

In the first model, the ions are assumed to be immobile and form a uniformly distributed background of positive charge. The electron gas is treated as an inertialess, pressureless, negatively charged fluid. This model is the the simplest physical MHD (magnetohydrodynamic) model. See for example JONES AND HUGRASS(1981) and the companion paper HUGRASS AND GRIMM(1981). In this model, the equation of motion of the electron gas and the generalised Ohm's Law are identical and read :

$$\mathbf{E} = \eta \mathbf{J} + \frac{1}{ne} \mathbf{J} \times \mathbf{B} \tag{1.1}$$

for a plasma of uniform electron density n and scalar resistivity η.

A rotating (or travelling) electromagnetic field is applied to the plasma via appropriately phased RF currents in coil structures external to the plasma. The amplitude, B_ω, and the angular frequency, ω, of this RF field are chosen so that :

$$\omega_{ci} \ll \omega \ll \omega_{ce}$$

where $\omega_{ci} = eB_\omega/m_i$ and $\omega_{ce} = eB_\omega/m_e$ are the ion and electron cyclotron frequencies in the applied field, B_ω. If the above inequality is satisfied, it is expected that the electrons will be entrained by the RF magnetic field whereas the ions are not. The plasma parameters and the amplitude of the RF field, B_ω, are chosen so that :

$$\nu_{ei} \ll \omega_{ce}$$

where ν_{ei} is the electron-ion momentum transfer collision frequency. The latter inequality ensures that the frictional force between the ions and electrons (due to collisions), is not so large that it impedes the motion of the electrons relative to the ions.

If the above inequalities are satisfied, it has been shown theoretically by JONES AND HUGRASS(1981) and HUGRASS AND GRIMM(1981), for the particular case of a transverse rotating magnetic field, that the applied field can fully penetrate the plasma column. This penetration of the field is accompanied by a synchronous rotation (in the Rotamak, or complete entrainment in Rythmac) of all the plasma electrons. The electrons can be regarded as being 'tied' to the field lines. Complete penetration of the applied field has been observed in high power, short duration Rotamak studies under certain experimental conditions, as reported by HUGRASS, JONES AND PHILLIPS(1981).

An alternative approach to the picture of electrons being 'tied' to field lines is obtained by considering the oscillatory electric field, $\tilde{e}$ and the oscillatory current density, $\tilde{\jmath}$, induced in the plasma by an externally imposed oscillatory magnetic field, $\tilde{b} = b_0 \sin \omega t$. It can be seen that in general the nonlinear Hall term will consist of a steady part and a part which oscillates at a frequency of 2ω. The steady component of Ohm's Law can then be written :

$$\mathbf{E}_0 = \eta \mathbf{J}_0 + \frac{1}{ne}\langle \tilde{\jmath} \times \tilde{b} \rangle + \frac{1}{ne}\mathbf{J}_0 \times \mathbf{B}_0 \tag{1.2}$$

where the subscript 'o' denotes time independent quantities and the angle brackets denote the time average (average over one RF cycle).

The physical constraints $\nabla \cdot \mathbf{J} = 0$ and $\nabla \cdot \mathbf{B} = 0$ imply respectively that there is no steady radial component of the current density or magnetic field. The force term arising from the interaction of the steady current with the steady field, $\mathbf{J}_0 \times \mathbf{B}_0$, has a radial component only.

From the above equation we see that even in the absence of imposed electric fields such as the inductively coupled toroidal field, E_ϕ, of the tokamak, we would expect that the nonlinear $\langle \tilde{\jmath} \times \tilde{b} \rangle$ Hall term could balance the resistive term to drive steady plasma currents.

A component of $\langle \tilde{\jmath} \times \tilde{b} \rangle$ can be used to drive a steady current provided the symmetry of the system is such that the generation of a counteracting electrostatic field is precluded.

The $\langle \tilde{\jmath} \times \tilde{b} \rangle$ current drive technique is used to drive the toroidal electron current in the Rotamak device. Nonlinear Hall effect current drive is also believed to be at work in a variety of conventional toroidal devices described later, in which several forms of external coil structures have been reported to drive substantial quasi-steady toroidal and/or poloidal current.

At this stage it is worth noting that the radial component of the time-averaged nonlinear Hall term $\langle \tilde{\jmath} \times \tilde{b} \rangle_r$ cannot be used to drive a steady current, but does provide a radial confining force. KONDO AND TOSHIOKA(1964) have proposed a confinement scheme in which a cylindrical plasma column is confined by a transverse rotating magnetic field. In this scheme the radial confining force is provided by $\langle\tilde{\jmath} \times \tilde{b}\rangle_r = \langle\tilde{\jmath}_z\tilde{b}_\theta\rangle$.

In the second theoretical model, the unrealistic assumption of fixed ions is relaxed. In order to prevent the model plasma from collapsing radially inwards, at least one of the plasma species must be endowed with a finite pressure. The problem of the ions being set into motion by electron-ion collisions (ion spin-up) also has to be addressed. One might imagine that in a completely isolated plasma, both ions and electrons would ultimately move in step with the field (causing the net current to vanish in time). This possibility is a feature of all RF current drive schemes. In practice, some ion-momentum relaxation mechanism such as charge exchange or the counterfeeding of fuel gas, must exist to ensure a net current.

HUGRASS(1982) has studied RMF current drive in a plasma cylinder using a mobile-ion model which endows both the ions and electrons with a finite pressure. His analysis shows that for a range of plasma parameters and suitable choices of the transverse rotating magnetic field amplitude and frequency, an ion-momentum relaxation mechanism with an effective frequency as low as, $\nu^* = m_e\nu_{ei}/m_i$, is sufficient to ensure a substantial net current.

As yet, we have not discussed the effect of a steady toroidal magnetic field on the current drive mechanism. BERTRAM(1987a) has studied the effect of a steady azimuthal magnetic field on RMF current drive. Under certain conditions, a strong externally applied field was found to substantially reduce the amount of driven current. In other cases, the presence of a toroidal field enhances the penetration of the RF magnetic field and increases the amount of driven current, as has been observed in recent experiments [HIRANO et.al.(1971); FUKUDA et.al.(1976)]. OSOVETS AND POPOV(1972) have driven Hall currents of a few kiloamperes in the presence of a relatively large (0.1T) toroidal magnetic field.

1.3 Review of $\langle \tilde{\jmath} \times \tilde{b} \rangle$ Current Drive.

In this section we will discuss the various experimental and theoretical studies of nonlinear Hall effect current drive. The review is essentially chronological. With the exception of the Rotamak, the review of experimental devices is focussed on machines with conventional toroidal geometry. The conventional torus devices are classified according to the poloidal number, m, of the external coils which are used to produce the travelling electromagnetic field. A large proportion of the material presented here can also be found in the recent review of $\langle \tilde{\jmath} \times \tilde{b} \rangle$ current drive by JONES(1986).

Due to the relatively large number of published Rotamak and rotating magnetic field (RMF) studies, a separate section is devoted to the discussion of this work. However, RMF current drive can be regarded as a special case of $m = 1$ RF travelling wave current drive.

1.3.1 m=0 Travelling Wave Experiments

The earliest reported observation of steady current drive by an RF travelling magnetic wave was made by THONEMANN et.al.(1952), using an $m = 0$ fully toroidal coil structure of the type shown schematically in Figure 1.1.

The coil structure is a tightly wound helix which is loaded by capacitors of equal value at fixed intervals in order to obtain a suitable value of the phase velocity on the delay line. The delay line is fed by an oscillator at one end whilst the other end is either short-circuited or terminated with the characteristic impedance of the line.

In these initial experiments a steady current in excess of 100A was observed in a toroidal Xenon plasma at a pressure of 1mTorr. The RF source was an oscillator capable of delivering 3-4kW of RF power at a frequency of 1.0MHz. No external toroidal or vertical magnetic fields were applied in this work.

Russian workers began to take an interest in $m = 0$ RF travelling waves during the late 1950's and the 1960's. DEMIRKHANOV et.al.(1962) first noticed $m = 0$

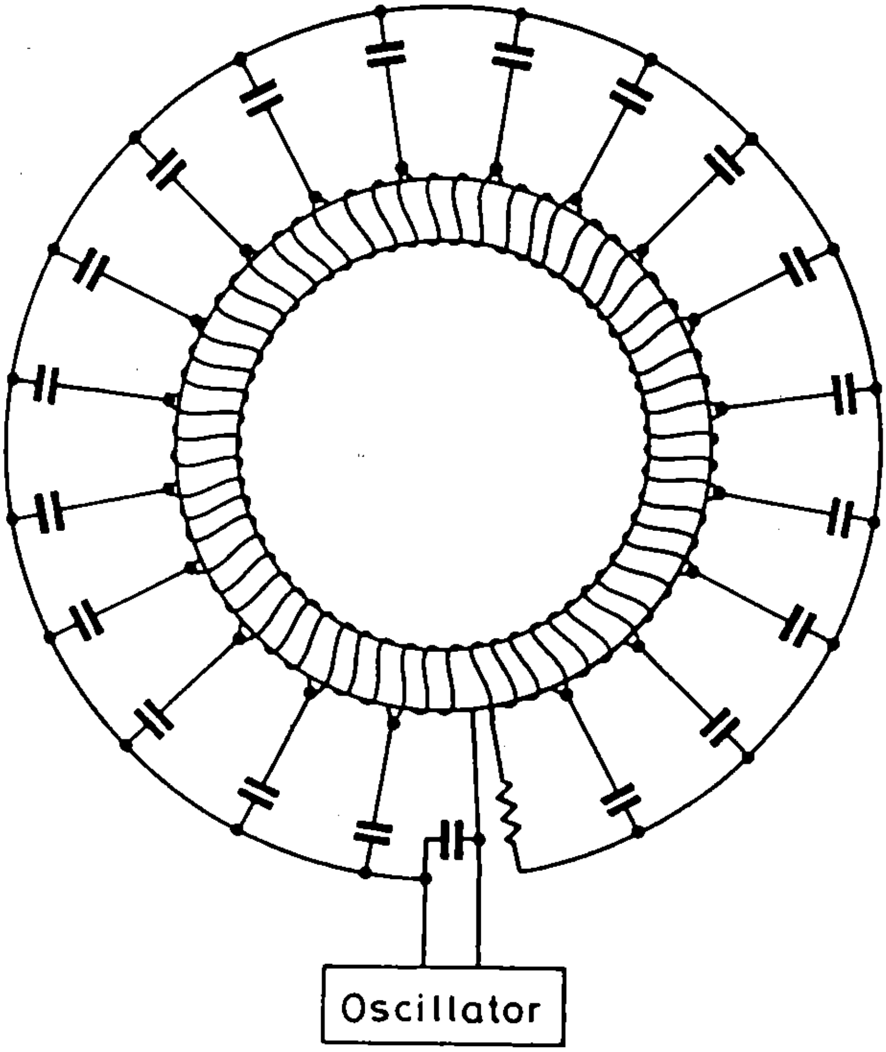

Figure 1.1 External structure for exciting a travelling $m = 0, k \neq 0$ electromagnetic wave.

current drive in experiments concerned with the possibility of containing plasma by a magnetic travelling wave. Later, DEMIRKHANOV et.al.(1965) turned their attention to the current drive phenomena. A detailed study was made of the dependence of the steady-state driven current on a wide range of parameters, including gas species, gas pressure, structure phase velocity, RF frequency and power input to the plasma.

The theory included in the latter paper [DEMIRKHANOV et.al.(1965)] demonstrates a full awareness of the role played by $\langle \tilde{\jmath}_\theta \tilde{b}_r \rangle$. A hollow current profile was predicted by this theory. The fact that a hollow current density was not observed in their experiments was attributed to averaging of the current density distribution over the cross section, as a result of electron thermal motion.

$m = 0$ RF current drive was also observed and studied at the I. V. Kurchatov Institute of Atomic Energy in Moscow, by BORZUNOV et.al.(1964). Experiments were conducted in the Volna device, which was very similar to but, larger than the device used by Demirkhanov and his colleagues. The Volna device was originally constructed to study plasma confinement. $m = 0$ RF travelling wave current drive research was continued at the Kurchatov Institute until the late seventies by OSOVETS AND POPOV(1972,1976).

In their first paper, OSOVETS AND POPOV(1972) studied $m = 0$, $\langle \tilde{\jmath} \times \tilde{b} \rangle$ current drive in the presence of a steady toroidal magnetic field. Until this point in time, all previously mentioned work was performed in the absence of a steady toroidal field. A generator with a pulse power of 60MW was used as the external RF current source. A vertical magnetic field was also provided for equilibrium. Volume excitation of Alfven waves was used to achieve increased RF field penetration and plasma heating. The use of a vertical magnetic field to control the position of the plasma along the major radius was the subject of later work by OSOVETS AND POPOV(1976).

During $\langle \tilde{\jmath} \times \tilde{b} \rangle$ current drive, the RF travelling magnetic field has been observed to penetrate the plasma column to a larger depth than predicted by the classical skin effect [see BORZUNOV et.al.(1964)]. As mentioned in Section 1.2, this effect is attributed to the influence of the nonlinear Hall term. This enhanced penetration of an RF travelling wave field into a plasma column has been theoretically modelled for the case of an $m = 0$ external structure by BREUS AND KURDYUMOV(1969) and IMSHENNIK et.al.(1969). The influence of the Hall effect on the penetration of an $m = 0$ travelling magnetic field into a plasma column has been experimentally verified in the toroidal Delta device by KHODATAEV et.al.(1970).

During the 1970's, RF current drive using $m = 0$ travelling waves was investigated at Nagoya University, Japan, in the toroidal Synchromak apparatus, ($R_0 = 25$cm, $a = 5$cm). Various experiments were conducted in which the helical delay line was wound either completely or partially around the torus. The coil structure differed from those used previously by other workers, in the method of terminating the delay line. The line was terminated with a matched 50Ω resistor (equal to the characteristic impedance of the line), rather than a short-circuit. The working gas in all the experiments was Argon.

Preliminary experiments at Nagoya University by HIRANO et.al.(1971) were performed with a fully toroidal RF coil structure and included a steady toroidal magnetic field of up to 150G (1G$\equiv10^{-4}$Tesla). The driven current was found to be maximized when a whistler wave was excited in the plasma.

FUKUDA et.al.(1976) studied the effect of local excitation by varying the length of the helical delay line. The plasma density, total driven toroidal current and the power absorbed by the plasma were each found to increase with increasing line length. However, the ratio I_{tor}/I_0 remained essentially constant. (Here I_0 represents the current which would be measured if all the plasma electrons were convected with the phase velocity, V_{ph}, of the wave field produced by the structure.) In the above experiments, the effect of electrostatically shielding the plasma from the RF coils was investigated. Electrostatic fields along the torus were found to play almost no role in the current drive mechanism, but did affect plasma production.

FUKUDA(1978) has measured the radial profile of the DC toroidal current which is driven in the Synchromak. The current density distribution was found to exhibit a noticeably hollow character. Current drive in the Synchromak device by $m = 0$ travelling waves has been numerically modelled using the $\langle \tilde{\jmath} \times \tilde{b} \rangle$ technique by HUGRASS(1981). Hollow DC current profiles similar to the experimental data were calculated.

The remaining experimental work in the Synchromak device [FUKUDA AND MATSUURA(1978)] was concerned with the relationship between the DC driven current and the RF power absorbed by the plasma. In this study, the gas filling pressure and the structure phase velocity were used as parameters. The driven current was found to be proportional to an effective electromotive force P_a/I_0, where P_a is the absorbed RF power and I_0 is as previously defined.

The DC current generated by an $m = 0$ travelling wave has been calculated by MIDZUNO(1973) for the case of a strong externally applied toroidal field. In this analysis, a single particle model was used to study the motion of a small number (10^4) of test electrons in the vacuum external field. Midzuno predicted that the main contribution to the driven current would be from electrons trapped in the train of travelling magnetic mirrors. However, this analysis is not self-consistent and is not expected to be applicable to typical laboratory plasmas with particle densities of $\sim 10^{18}\mathrm{m}^{-3}$, which are better described by a fluid model. A self-consistent MHD fluid description such as the $\langle \tilde{\jmath} \times \tilde{b} \rangle$ model of RF current drive, predicts that an externally applied travelling electromagnetic wave of suitable amplitude and frequency can be used to entrain *all* of the plasma electrons, rather than a small subgroup of electrons whose thermal velocity is close to the wave phase velocity.

1.3.2 m=1 Travelling Wave Experiments.

HOTTA et.al.(1985) and SUZUKI et.al.(1985) have driven a bulk current in the TPX-W2 device at the Tokyo Institute of Technology by means of a $m = 1$ helical travelling RF magnetic field. The external coil structure used to produce the RF magnetic field is shown in Figure 1.2. Two pairs of $m = 1$ windings are placed $\pi/2$ apart in the

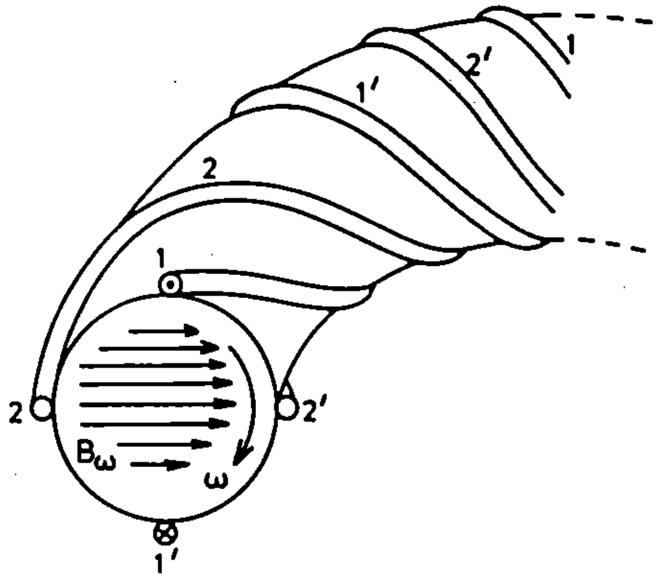

Figure 1.2 External structure used to excite an $m = 1, k \neq 0$ helical travelling wave.

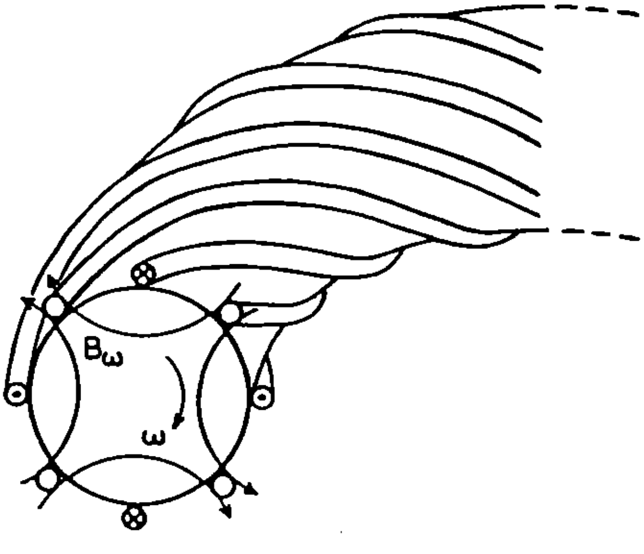

Figure 1.3 External structure used to excite an $m = 2, k \neq 0$ helical travelling wave.

θ direction and fed by separate RF sources of the same amplitude and frequency, but dephased by one quarter of a period. The RF fields produced by this structure progress in both the toroidal and poloidal directions (so that both toroidal and poloidal current drive is possible).

In the experiments mentioned above, the coil structure was wound on one third of the torus. The remaining two thirds of the torus was enclosed by a copper conducting shell. A strong toroidal magnetic field was applied.

Asymmetry introduced by the presence of a steady toroidal field, B_{tor}, gives rise to the possibility of imposing two types of RF magnetic field. The two types of external RF magnetic field are denoted $m = +1$ and $m = -1$. In the $m = +1$ (or diamagnetic) configuration, the travelling helical magnetic field progresses in a right-handed screw fashion with respect to B_{tor} (the direction of electron diamagnetic drift). The poloidal current driven by the $m = +1$ coils produces a toroidal magnetic field in the opposite direction to the applied toroidal field. In the $m = -1$ (paramagnetic) configuration the structure field progresses in a left-handed screw fashion with respect to B_{tor}, and the toroidal field produced by the steady driven poloidal current is in the same direction as the applied toroidal field. A diamagnetic configuration can be converted to a paramagnetic configuration and vice versa, by reversing the direction of the external toroidal magnetic field or by changing the relative phase of the two RF sources from $\pi/2$ to $-\pi/2$.

Recent experiments at Flinders University by DUTCH AND MCCARTHY(1986a,b) have demonstrated that a fully toroidal $m = 1$ helical coil structure can be used to drive both toroidal and poloidal current by means of the nonlinear Hall effect. Although it was not reported, it is expected that some poloidal current would also have been driven in earlier $m = 1$ experiments conducted in the TPX-W2 device. The interaction of the steady poloidal current with the steady toroidal magnetic field may play an important role in the equilibrium of the plasma. This interaction could also account for the large differences in the magnitude and distribution of

I_{tor} between corresponding diamagnetic and paramagnetic configurations, which have been observed in the experiments. [see for example, **Suzuki** et.al.(1985).]

The desire to control the amount of poloidal current driven in $m = 1$ experiments has led **Dutch and McCarthy**(1987) to develop a 'Helical Mesh' coil structure designed to drive purely toroidal bulk current. The $m = +and-1$ helical mesh antenna consists of a series connected superposed set of $m = +1$ and $m = -1$ helical coils. A schematic diagram of the helical mesh antenna can be found in Figure 3.9c.

1.3.3 m=1 Rotating Magnetic Field Studies.

The Rotating Magnetic Field (RMF) used to drive azimuthal current in a plasma cylinder can be regarded as a special case of an $m = 1$ helical travelling electromagnetic wave. A transverse rotating magnetic field is obtained in the limit $k = 0$, where k is the axial wavenumber of the external coils. In this limit, the RF conductors are straight and parallel.

The first report of a rotating magnetic field being used to drive a steady azimuthal current in a plasma cylinder was given by **Blevin and Thonemann**(1962). The theoretical model of the current drive scheme which was presented by the authors clearly identifies the role played by the nonlinear Hall term in Ohm's Law. The experimental work of Blevin and Thonemann at the U.K.A.E.A. Culham Laboratory was continued by **Davenport** et.al.(1966). Experimental studies of plasma confinement using a RMF have been reported by **Merard and Pottier**(1962) and **Schubaly and Skarsgard**(1975).

Early theoretical investigations focussed on a number of phenomena associated with the application of a transverse rotating magnetic field to a plasma cylinder. **Volkov**(1964) studied the penetration of a RMF into a plasma column. Plasma confinement with a RMF was the subject of a paper by **Kondo and Toshioka**(1964). Electron entrainment by a small amplitude transverse RMF was examined by **Sidorov and Soldatenkov**(1966).

The RMF current drive technique is currently being used at Flinders University and at the Australian Atomic Energy Commission (AAEC), to generate and maintain the toroidal current in a compact torus device known as the Rotamak.

Since Rotamak research was initiated at Flinders University in 1978 and at the AAEC in 1982, the program has systematically developed a theoretical understanding of the physical principles involved in the rotating magnetic field current drive scheme. Stable reproducible compact torus configurations of various geometries have been produced in a number of devices under a range of experimental conditions. The steady magnetic field structures of various Rotamak equilibria have been measured in detail and carefully analysed with reference to the $\langle \tilde{\jmath} \times \tilde{b} \rangle$ current drive theory. [see for example DURANCE(1983), KIROLOUS(1986)]. The success of the Rotamak program is indicated by the relatively large list of publications, which nows totals somewhere in excess of forty. Some of the work contained in these papers is summarised below.

An informative review of. Rotamak research until 1983 can be found in DURANCE(1983). The Rotamak concept was first described by JONES(1979). The first published experimental results [HUGRASS et.al.(1980)] were obtained in a small (12.8cm diameter) spherical Pyrex discharge vessel using two high power ($\sim$ 6MW), short-duration ($\sim 15\mu$s) modified Weibel Line Generators.

Steady state solutions for the penetration of a rotating magnetic field into a plasma column have been obtained by JONES AND HUGRASS(1981). A time-dependent analysis of RMF current drive has been performed by HUGRASS AND GRIMM(1981). Results of complementary high-power, short-duration and low-power, long-duration Rotamak experiments performed at Flinders University are summarised in the paper by DURANCE et.al.(1982).

One of the main goals of the Rotamak research program is to produce high-temperature, long-duration compact torus configurations. With this in mind, moderately high power ($\sim$ 100kW per phase), long-duration (40ms-Flinders; 10ms-AAEC) RF amplifiers have been constructed and used in recent experiments. Higher power

(400kW per phase) RF amplifiers are currently under construction at Flinders University.

Numerous theoretical studies of the RMF current drive technique have been made in recent years. HUGRASS(1982) has used a mobile ion model to study cylindrical plasma equilibria maintained by RMF. Numerical calculations of the electron and ion orbits in the self-consistent fields of the Rotamak [HUGRASS AND TURLEY(1987)] and an infinitely long cylindrical plasma equilibrium maintained by RMF [HUGRASS AND JONES(1983)] have shown that in each case the particles are confined although the lines of instantaneous magnetic field are open. A similar result is expected to be found in the Rythmac device, although the theory has yet to be developed.

A series of studies by W.N.Hugrass have elucidated power and momentum relations in RMF current drive [HUGRASS(1984), based on the work of KLIMA(1973)], the existence of non-unique steady-state solutions to the RMF current drive equations [HUGRASS(1985)] and the influence of higher order spatial harmonics on the RMF current drive [HUGRASS(1986)]. Non-unique solutions to the current drive equations are also found in the present work.

1.3.4 m=2 Travelling Wave Experiments

RF current drive using $m = 2$ coil structures was studied in the early 1980's by DEMIRKHANOV et.al.(1981,1982) at the Sukhumi Institute of Physics and Technology (USSR) and also at the Tokyo Institute of Technology (Japan), by KIKUNAGA et.al.(1982) and HOTTA et.al.(1984). The external coil structure which is used in these experiments is shown schematically in Figure 1.3.

The profile of the steady toroidal current driven with this structure is found to be hollow; see DEMIRKHANOV et.al.(1981). This is a common feature of all RF travelling wave current drive schemes with $m \neq 1$. In these configurations, symmetry demands that the transverse components of the externally applied RF magnetic field and the induced plasma screening currents must vanish at the axis. Consequently, there is no

$\langle \tilde{\jmath} \times \tilde{b} \rangle$ current drive near the axis. For the special case of an applied RF field with $m = 1$ symmetry, the radial components of the RF fields and currents in the plasma may be non-zero on the axis. Hence, this configuration may be used to drive a steady bulk longitudinal plasma current.

1.4 Outline of Thesis

The work reported in this thesis extends the study of nonlinear Hall effect current drive to a device with conventional toroidal geometry. In making this transition, we have drawn on the results of experimental and theoretical Rotamak studies at Flinders University. The objective of the present work was to investigate the use of the nonlinear Hall effect $\langle \tilde{\jmath} \times \tilde{b} \rangle$ current drive technique to produce stable, reproducible discharges in a conventional torus.

The RF sources used in the present work were high-power, short-duration modified Weibel line generators. Current drive using both $m = 0$ and $m = 1$ RF coil structures was studied. Detailed measurements have been made of the quasi-steady magnetic field structure of several reproducible discharges produced in Argon by the $m = 1$ helical coil structures. The effect of various parameters on the total driven toroidal current and/or the magnetic field structure of the discharge was investigated. Parameters studied included the filling gas pressure, the strengths of the steady applied toroidal and vertical magnetic fields, and the type and extent of the external RF coil structure used.

A review of RF current drive in conventional toroidal geometry using external coil structures is presented in Chapter 1.

In order to model the $m = 1$ double helix experiments and to gain a better understanding of the $\langle \tilde{\jmath} \times \tilde{b} \rangle$ current drive mechanism, a theoretical description for the case of external coils with $m = 1$, $k \neq 0$ is developed in Chapter 2. For simplicity, a large-aspect-ratio cylindrical model is adopted, in which the ions are assumed to be immobile. The electron gas is treated as a pressureless, inertialess, negatively charged fluid.

The experimental apparatus is described in Chapter 3. Details of the diagnostics and data acquisition system are given in Chapter 4. In Chapter 5, the experimental results are presented. Finally, in Chapter 6, the results are discussed and some conclusions regarding further work are drawn.