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Magnetic field measurements for N_2 and H_2 discharges from a low frequency RF inductively coupled plasma source

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Abstract

The electric field due to a strong capacitive coupling between the induction coil and the walls of the plasma chamber is quite large despite the discharge being in the H-mode in N_2 and H_2 gases. And as such, this field will interfere with the measurement of the magnetic field thus causing a high degree of measurement error. This paper hence describes the use of a centre-tapped coiled magnetic probe for the measurement of magnetic field profiles in 1-D in the low frequency RF inductively coupled plasma source. From these profiles, an independent method to determine the average electron density is also shown.
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Keywords: Magnetic probes; H-mode; E-mode; Fields; RF ICP

1. Introduction

The presence of E- and H-mode discharges [1] in induction plasma systems has been reasonably well understood since the late 1920s. The E-mode is a capacitive coupled mode and the discharge is driven by the electrostatic field, which exists, between the turns of the induction coil. The onset of the H-mode is due to an induced azimuthal electric field, which drives the secondary current in the plasma. E-mode behavior predominates in induction systems at very low RF powers and high filling pressures (depending on the types of gases). It has been shown in the work by Chakrabarty [2], which capacitive and inductive coupling do co-exist in N_2 and H_2 discharges in a wide range of filling pressure. The capacitive coupling has been shown to be increasing with the increase in the filling pressure of these gases. Typically, this discharge mode has plasma densities lower by more than one order of magnitude in comparison to H-mode discharges. Due to the lowering of these densities, the electrostatic fields are not quite shielded by the bulk plasma in the chamber and as such will contribute to measurement errors when magnetic fields are measured in the plasma using the simple coiled magnetic probes. In order to minimize the effects of parasitic electrostatic pick-up in these probes, the centre-tapped coil configuration was implemented for the measurements.

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2. Methods

Fig. 1 illustrates the basic structure of the magnetic probe used for magnetic field measurements. To obtain the centre-tapped configuration, two lengths of wire were wound together, after the end of wire A was connected to the beginning of wire B and both were connected to the ground terminal. The other terminals (of A and B in Fig. 1) were connected to the input of the differential amplifier which is shown in Fig. 2; its operation is to sum the magnetic signals (M) while subtracting the electrostatic signals (E). It works as follows:

Let the signal from coil A be ($M_A + E_A$). In the centre-tapped configuration shown in Fig. 1, the signal from coil B is then ($-M_B + E_B$). The output signal (V_N) from the differential amplifier is thus given by

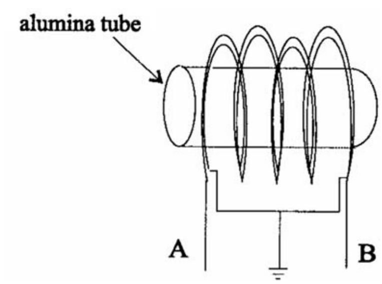

Fig. 1. The centre-tapped magnetic probe.

$$V_N = M_A + E_A - (-M_B + E_B)$$
$$= M_A + M_B + (E_A - E_B). \quad (1)$$

In principle, for a symmetrical centre-tapped coil, $E_A = E_B$ and $M_A = M_B$. From this, and using Eq. (1), $V_N = 2M_A$.

Credible measurements of magnetic fields having amplitudes which varied by a factor ~150 could only be made by incorporating a Butterworth low-pass filter [3] not shown in the figure. Its 800 kHz cut-off frequency suppressed the high-frequency 'noise' which polluted the low-level probe signals. The probe was calibrated and has a calibration constant of 4.62 Gauss/volt at 0.56 MHz which is the operating frequency of the RF generator that produces the plasma.

In practice, the magnetic probe was wound on an alumina core of 1 mm diameter; the coil wire was enamel coated and 0.1 mm in diameter. The probe coil was then located within a re-entrant fused silica which entered the plasma chamber as shown in Fig. 3 through the probe port. Compressed air was channelled into the silica tube to cool the magnetic probe when measurements were made during plasma operation.

Magnetic field (B_Z) measurements were performed along the z-axis (i.e., $r = 0$; see Fig. 3 for co-ordinate system) of the plasma chamber. The measurements were performed separately in vacuum, 40 mtorr of N_2 and 40 mtorr of H_2. The current $\hat{i}$ through the induction coil that generates the

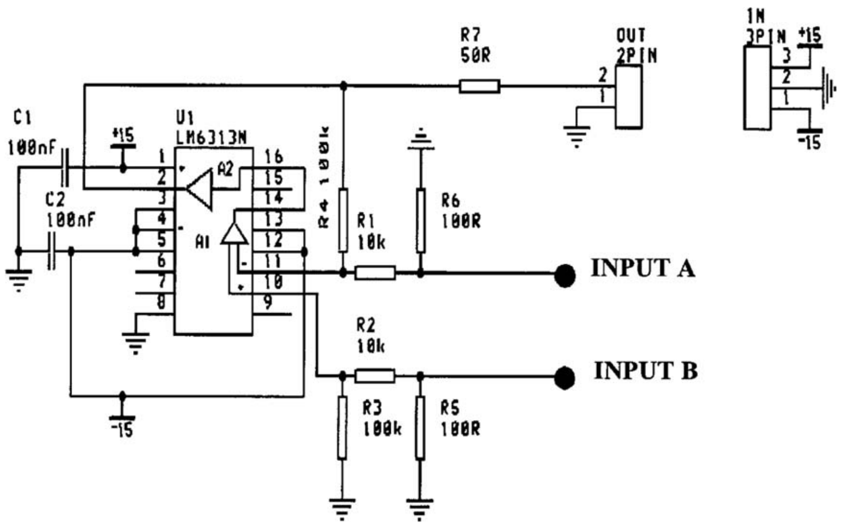

Fig. 2. The differential amplifier circuit.

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