Development of a High CMRR Magnetic Probe for the Biased Plasma in TU-Heliac

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The plasma in Tohoku University Heliac (TU-Heliac) is biased by a hot cathode that drives the $\boldsymbol{J} \times \boldsymbol{B}$ poloidal rotation. In the biased plasma, a density collapse accompanied by high-frequency bursting density and potential fluctuations was observed. To eliminate the effect of potential fluctuations and to measure the magnetic fluctuation, a high common mode rejection ratio (CMRR) magnetic probe with a preamplifier at the probe head in a vacuum vessel was designed and installed. Owing to the absolute calibration, the magnetic probe has a high magnetic sensitivity of 10^4 V/T (@100 kHz), high CMRR of −75 dB (@500 kHz), and frequency bandwidth DC −1 MHz. In the biased plasma, the power spectrum of the normal mode signal was 10^4 times larger than that of the common mode signal in all frequency ranges, which indicates that the probe can successfully minimize the capacitive pickup noise relative to the actual magnetic fluctuation signal. In addition, we successfully observed the broad spectrum (100 kHz $< f <$ 300 kHz) of the magnetic fluctuation and MHD instability in the biased plasma in TU-Heliac.

Keywords: magnetic probe, biased plasma, MHD, fluctuation, density collapse

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We performed electrode biasing experiments in Tohoku University Heliac (TU-Heliac), and successfully controlled the radial profile of the space potential and poloidal plasma flow by an external driving force $\boldsymbol{J} \times \boldsymbol{B}$, where $\boldsymbol{J}$ and $\boldsymbol{B}$ are the electrode current and confinement magnetic field, respectively [1]. In the biased plasma, a steep plasma potential profile forms quickly and various potential fluctuations exist. To survey the characteristics of the MHD fluctuations in biased plasmas, developing a magnetic probe that avoids signal coupling to quickly changing electrostatic potentials and potential fluctuations is important. Some precautions ought to be undertaken to reduce the capacitive pickup in comparison to the actual magnetic fluctuation signal, e.g., an electrostatic shield, a transformer coupling, or a balanced transmission line, *etc*. [2].

In TU-Heliac, we observed that density collapse accompanied high-frequency bursting fluctuations [3]. To survey the characteristics of the MHD fluctuations, we developed a magnetic probe sensitive to magnetic fluctuations and insensitive to capacitive pickup noises. To eliminate the effect of potential fluctuations, we adopted a fully differential amplifier (THS4131, Texas Instruments), which was placed at the probe head in a vacuum vessel, as illustrated in Fig. 1. The magnetic pickup coil comprises thirty turns with a radius of 1.9 mm and is connected to the fully differential amplifier by a shielded twisted pair cable via a 100 Ω resistor. The signal is transferred through the shielded twisted pair cable and is connected to an oscilloscope by coaxial cables through the isolated amplifiers. The fully differential amplifier has advantages that enable us to simultaneously measure both the normal mode signal produced by the electromagnetic induction and the common mode signal caused by capacitive pickup, and to compare each signal level directly. This type of amplifier also has the capability to reduce the common mode signal owing to the effect of the balanced transmission without an electrostatic shield for the magnetic pickup coil or a transformer coupling.

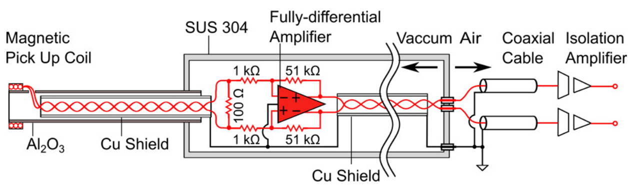

Fig. 1 Schematic of magnetic probe.

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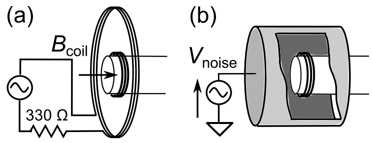

Fig. 2 (a) Schematic of the magnetic sensitivity calibration and (b) CMRR measurement.

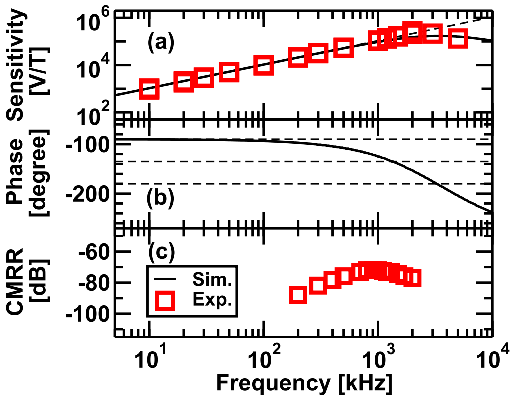

Fig. 3 (a) The frequency dependence of the magnetic sensitivity, (b) phase difference between magnetic field B_{coil} and normal mode signal V_{normal}, and (c) CMRR measurements.

The absolute calibration of the magnetic sensitivity and capacitive pickup sensitivity for the magnetic probe was performed. The schematic diagrams of the calibration setup are presented in Figs. 2 (a) and 2 (b). As presented in Fig. 2 (a), the coil for the magnetic field calibration comprises a ten turn winding with a radius of 65 mm. The coil current was fixed to 0.1 A via a resistive load (330 Ω) in the frequency range 10 kHz $\leq f \leq$ 5 MHz. The magnetic field strength at the coil center, B_{coil}, was 0.01 T. The magnetic sensitivity is defined as V_{normal}/B_{coil}, where V_{normal} represents the normal mode signal. As presented in Fig. 2 (b), the probe was surrounded by a Faraday cup, 38 mm in diameter and 78 mm in length. As the electric field inside the Faraday cup is nearly homogeneous, a well-defined electric field is provided for the capacitive pickup sensitivity measurements. The voltage applied to the Faraday cup, V_{noise}, was fixed to 100 V in the frequency range 200 kHz $\leq f \leq$ 2 MHz. The capacitive pickup sensitivity can be used to evaluate the common mode rejection ratio (CMRR), which is defined as V_{normal}/V_{noise}. In Fig. 3, we present (a) the frequency dependence of the magnetic sensitivity, (b) the phase difference between V_{normal} and B_{coil}, and (c) the CMRR measurements. In Fig. 3 (a), the solid line denotes the simulation results with the circuit simulator LTspice [4]. The magnetic sensitivity shows the linear dependence on frequency (f < 2 MHz) because the magnetic induction is proportional to frequency. Moreover, the magnetic sensitivity is saturated in the frequency range f > 2 MHz because of the bandwidth in the amplifier gain. The phase difference presented in Fig. 3 (b) is −135 degree at ∼ 1.3 MHz and −180 degree at ∼ 3 MHz. The CMRR illustrated in Fig. 3 (c) depends linearly on frequency (f < 1 MHz) because the probe coil is coupled to potential sources via the stray capacity and decreases in the frequency range (f > 1 MHz). In summary, we developed a magnetic probe with a high magnetic sensitivity of 10^4 V/T (@100 kHz), high CMRR of −75 dB (@500 kHz), and frequency bandwidth DC −1 MHz without an electrostatic shield.

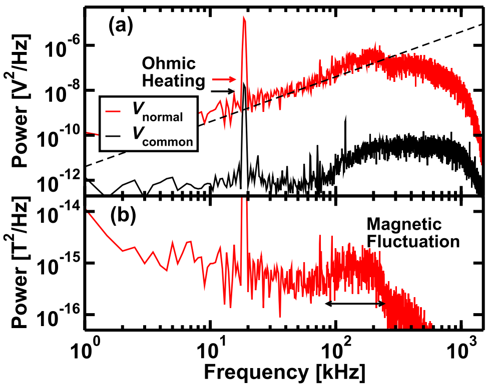

Fig. 4 (a) The power spectra of normal mode signal V_{normal} and common mode signal V_{common} at $\rho \sim 0.2$ and a square of frequency (dash line) and (b) the power spectra of magnetic field fluctuation.

To investigate the magnetic fluctuation in the biased plasma in TU-Heliac, the magnetic probe was installed and we measured the radial component of the magnetic fluctuation $\tilde{B}_r$ at $\rho \sim 0.2$. The target plasma was produced by alternate ohmic heating (f = 18.7 kHz) in TU-Heliac. The working gas was helium. The typical electron temperature, electron density, and poloidal flow velocity of the electrode biasing plasma were ∼20 eV, $\sim 10^{18}$ m^{-3}, and ∼5 km/s [1]. The power spectra of the normal mode signal, V_{normal}, and the common mode signal, V_{common}, were calculated using complex Fourier transform, as presented in Fig. 4 (a). The peak in the power spectra at 18.7 kHz in the normal and common mode signals is owed to the alternate ohmic heating. From Fig. 4, the power spectra of the normal mode signal was 10^4 times larger than that of the common mode signal in all frequency ranges, which indicates that we can successfully minimize the capacitive pickup noise relative to the actual magnetic fluctuation signal without an electrostatic shield for the magnetic pickup coil. The power spectrum of the floating potential measurement by using a Langmuir probe was $\sim 10^{-5}$ V^2/Hz in this frequency range. The power spectrum of the normal mode signal is proportional to the square of frequency (f < 100 kHz) because of the frequency dependence of the magnetic sensitivity. Figure 4 (b) illustrates the power spectrum of the magnetic fluctuation converted from the power spectrum of the normal mode signal considering the frequency dependence of the magnetic sensitivity. In addition we successfully observed the broad spectrum (100 kHz $< f <$ 300 kHz) of the magnetic fluctuation and MHD instability in the biased plasma in TU-Heliac.

[1] S. Kitajima *et al.*, Nucl. Fusion **46**, 200 (2006).
[2] C.M. Frank *et al.*, Rev. Sci. Instrum. **73**, 3768 (2002).
[3] Y. Tanaka *et al.*, Plasma Fusion Res. **3**, S1055 (2008).
[4] www.linear.com