Improvement of the Reynolds Stress Probe for End-Plate Biasing Experiments in a Cylindrical Laboratory Plasma

Tomotsugu KANZAKI, Yoshihiko NAGASHIMA[1)], Shigeru INAGAKI[1)], Fumiyoshi KIN, Yudai MIWA, Makoto SASAKI[1)], Takuma YAMADA[2)], Akihide FUJISAWA[1)], Tatsuya KOBAYASHI[3)], Naohiro KASUYA[1)], Yusuke KOSUGA[4)], Sanae-I. ITOH[1)] and Kimitaka ITOH[3)]

Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Kasuga, Fukuoka 816-8580, Japan
[1)]Research Institute for Applied Mechanics, Kyushu University, Kasuga, Fukuoka 816-8580, Japan
[2)]Faculty of Arts and Science, Kyushu University, Kasuga, Fukuoka 819-0395, Japan
[3)]National Institute for Fusion Science, Toki, Gifu 509-5292, Japan
[4)]Institute for Advanced Study, Kyushu University, Kasuga, Fukuoka 812-8581, Japan

(Received 18 March 2016 / Accepted 15 April 2016)

We improved the signal-to-noise ratio of a Reynolds stress (RS) probe in order to measure the Reynolds stress more accurately. By introducing a shield pipe in the probe, the power spectral density of the noise was suppressed to approximately one tenth in an electric biasing experiment. It was also confirmed that the leak current in the RS probe, which had been used in previous experiments, was small enough for the study of drift waves in our linear device.

Keywords: linear device, probe, electric bias experiment, Reynolds stress

DOI: 10.1585/pfr.11.1201091

Recently, interactions between microscopic drift wave fluctuations and meso- and macro-flows in magnetized plasmas have been studied thoroughly [1, 2]. Detailed observations, including direct observations of the nonlocal energy exchange between fluctuations and flows [3], on the linear magnetized plasmas using Langmuir probes have been made [1, 4]. Nonlocality has been widely studied [5, 6]; therefore, the correlation functions at different positions must be accurately measured. In the probe measurement, a small but finite interference between the signal at the probe position and the fluctuation field along the ‘stem’ of the probe could occur. Such interference must be minimized in order to obtain reliable data to study the interactions of fluctuations at different positions. In this article, we report a new multi-channel Reynolds stress probe system (RS probe), in which the crosstalk through the stem of the probe is reduced. By applying this new probe to Plasma Assembly for Non-linear Turbulence Analysis (PANTA) plasmas [7], we demonstrated that the noise power is reduced by an order of magnitude. The novelty of this study is a quantitative measurement of the leak current along the stem of the probe. This is an essential achievement in developing RS probes for studying nonlocal interactions of microscopic fluctuations [8] in basic experimental devices.

PANTA is a linear magnetized plasma device in which the plasma is produced by helicon waves (3 kW / 7 MHz). The cylindrical vacuum vessel has a diameter of 45 cm and a length of 400 cm. The plasma diameter is about 10 cm. The parameters of the present experiments are as follows: magnetic field $B = 0.08$ T, plasma density $n = 1 \times 10^{19}\,\mathrm{m}^{-3}$, electron temperature $T_e = \sim 3.0$ eV, ion temperature $T_i = \sim 0.3$ eV, filling neutral gas pressure $P_n = 0.85$ mTorr. The electron density gradient is steep in the region of $r = 3$ - 4 cm. Drift waves are excited and propagated in the electron diamagnetic direction (positive azimuthal direction in this study). In this study, an end-plate electrode with a diameter of 5 cm was used for the biasing experiment (see, e.g., [9] for details) and a bias voltage of 40 V.

Schematic of the circuit of the probe is shown in Fig. 1 (a). The long cable (8 m) capacitances, C_1, and short cable (~0.6 m) capacitances, C_2, are 800 pF and 60 pF, respectively. We selected R_1 to be a 50 Ω resistor in order to effectively cancel the capacitance of the long cable. We also selected R_2 to be a 100 kΩ resistor (much larger than the sheath impedance $R_{sh} = T_e\,[\mathrm{eV}]/I_{is}\,[A] \sim 300\,\Omega$, which is calculated from a T_e value of 3 eV and a I_{is} value of 10 mA). The capacitance of the sheath can be estimated as $C_{sh} \approx \varepsilon_0 A/\lambda_D$ [10]. We estimated $C_{sh} = 65$ pF.

We improved the probe to strongly reduce the crosstalk by introducing a shield pipe between the ceramic tube and the electrode. The scheme is shown in Fig. 1 (b). By connecting the shield pipe to the electrical ground, the electric shielding of the electrode from plasmas surrounding the stem of the probe is improved. The electrical cur-

author’s e-mail: kanzaki@panta.riam.kyushu-u.ac.jp

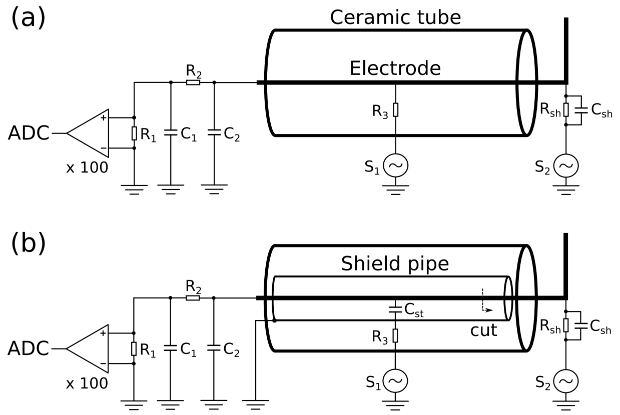

Fig. 1 (a) Conventional guarding circuit of the RS probe. (b) Novel guarding circuit of the RS probe. $R_1 = 50\,\Omega$, $R_2 = 100\,\text{k}\Omega$, $R_3 = {\sim}20\,\text{M}\Omega$, $C_1 = 800\,\text{pF}$, $C_2 = 60\,\text{pF}$, and $C_{sh} = 65\,\text{pF}$. S_1 and S_2 mean the plasma. S_2 is closer to the inside of the plasma than S_1.

rent through the ceramic pipe is reduced due to the finite resistance and capacitance. We adopted Steel Use Stainless (SUS) pipes as shield pipes to withstand the high heat flux. A polyimide tube is used as an insulator between the shield pipes and electrodes. No heat endurance problem was noted on using the polyimide tube in the experiment.

The effect of the shield pipe was examined using the new (with shield) and conventional (without shield) probes. The difference between the new and conventional probes indicates a reduction of the leak current across the stem of probes. We also prepared two dummy electrodes, whose tips were cut 1 cm below the heads, with and without the shield pipe. These dummy electrodes do not attach to the plasma and collect the currents flowing across the stem, which contribute to the crosstalk. An end-plate bias voltage of 40 V was applied for 0.35 s - 0.50 s, and the RS probe was located at $r = 3$ cm. The experimental results are shown in Fig. 2. Figure 2 (a) shows a comparison between the floating potentials of the new (red) and conventional (black) probes. The signal from the new probe is a slightly smaller than that obtained with the conventional probe during biasing. However, the difference is approximately a few %. The radial locations of the normal and dummy electrodes are almost the same, and the difference could be caused by the reduction of the leak current, witch is confirmed by observing the difference between signals of the two dummy electrodes. Figure 2 (b) shows the result of the dummy electrodes with (red) and without (black) shield. A significant reduction of the noise signal for the case with the shield pipe is demonstrated. The data from the dummies show that the shield pipe suppresses the noise amplitude to approximately one-fifth (before biasing) or one-fourth (during biasing). In addition, the absolute value of the signal of the dummy electrode is approximately 1% of that of the probe, indicating that the leak current across

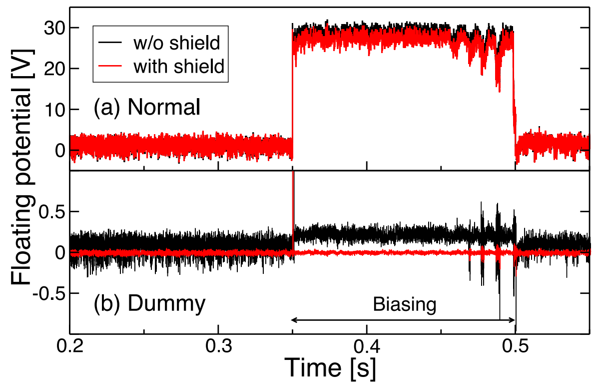

Fig. 2 Time evolution of floating potential. Black lines show the case without the shield pipe and red ones show the case with shield pipe. (a) Normal electrodes (b) Dummy electrodes.

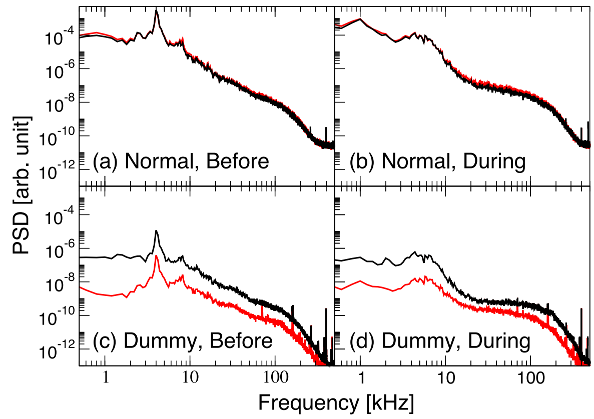

Fig. 3 PSDs of normal electrode signals in the period before (a) and during (b) biasing. (c) and (d) show PSDs of dummy electrode signals before and during biasing, respectively. In (a) - (d), the red and black lines indicate PSDs of signals measured with and without shield, respectively.

the stem is small even in the conventional probe.

Furthermore, we calculated the power spectral density (PSD) to confirm the noise reduction by the shield probe over a wide frequency range. Figure 3 shows PSDs of potentials obtained from probes with (red lines) and without (black lines) shields. Moreover, PSDs before ($0.25\,\text{s} < t < 0.35\,\text{s}$) and during biasing ($0.35\,\text{s} < t < 0.45\,\text{s}$) calculated from the data are shown in Fig. 2. In Figs. 3 (a) and (b), the PSDs of probes with and without shields look approximately the same before and during the biasing over the wide frequency range. We consider that the signals of the dummies indicate noise owing to the leak current across the stem. In the case of the unshielded probe (see black lines in Fig. 3), the PSDs obtained for the dummy (i.e., PSDs of noise) are 1% of that for normal electrodes (i.e., the amplitude amounts to 10%). This level of noise (1%) could be a large obstacle for studying the nonlocal interactions of microscopic fluctuations. On the other hand, the noise is successfully reduced by 1 - 2 orders of magnitude by the new shielded-probe (see red lines in Figs. 3 (c) and (d)). We conclude that the shield pipe can eliminate the crosstalk noise significantly without reducing the high frequency components of the signal.

This study is partly supported by a Grant-in-Aid for scientific research of JSPS, Japan (26420852, 15H02335, 15H02155, 23244113), the collaboration programs of the RIAM of Kyushu University and NIFS (NIFS13KOCT001), and Asada Science foundation.

[1] S.-I. Itoh *et al.*, Plasma Fusion Res. **90**, 793 (2014).
[2] P.H. Diamond *et al.*, Plasma Phys. Control. Fusion **47**, R35 (2005).
[3] Y. Nagashima *et al.*, Phys. Plasma **16**, 020706 (2009).
[4] S.-I. Itoh, J. Plasma Fusion Res. **86**, 334 (2010).
[5] S. Inagaki *et al.*, Phys. Rev. Lett. **107**, 115001 (2011).
[6] K. Ida *et al.*, Nucl. Fusion **55**, 013022 (2015).
[7] Y. Nagashima *et al.*, Rev. Sci. Instrum. **82**, 033503 (2011).
[8] S. Inagaki *et al.*, Nucl. Fusion **54**, 114014 (2014).
[9] T. Yamada *et al.*, Nucl. Fusion **54**, 114010 (2014).
[10] C. Theiler *et al.*, Rev. Sci. Instrum. **82**, 103504 (2011).