DESIGN AND FABRICATION A NOVEL PROBE IN IR-T1 TOKAMAK

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In this paper, the first results of plasma parameters measurement by using the moveable Multi-purpose probe (MPP) have been investigated and discussed. Multi-purpose probe was designed, constructed, and installed on the IR-T1 Tokamak for the first time. This probe can simultaneously measure electric and magnetic fluctuations in three directions: poloidal, radial and toroidal. The Multi-purpose probe is composed of three sections: electrical part, magnetic part and the flow measurement section. The relation between Reynolds stress gradient and poloidal particle flux can be investigated by Multi-purpose probe. It is quite compact and does not strongly disturb plasma. In this paper, we have investigated and discussed about plasma parameters as the temporal and space evolutions of the plasma potential, Reynolds stress, poloidal particle flux, flow velocity, electrostatic fluctuations and magnetic fluctuations. The results show that the radial electric field has its maximum amount in the last Closed Flux Surface (LCFS) while poloidal electric field is minimum at this point. Also, the Reynolds stress is minimum at LCFS. The results show that decrease of the Reynolds stress cause to the remarkable increase of the poloidal particle flux. The radial electric field and poloidal flow values have been changed in the vicinity of the LCFS. This means that Reynolds stress can suppress turbulence and modify turbulence transport.

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INTRODUCTION

Recent progress in the control of plasma turbulence and transport in magnetically confined plasmas has opened a new era in plasma transport physics research [1, 2]. It has been recognized that the cross-field plasma transport through the edge is dominated by turbulence [3-5]. Turbulence is responsible for anomalously high losses of particles and energy in the edge plasma. In order to suppress the negative effects caused by turbulence, proper understanding of the phenomena occurring in the plasma edge is needed [6]. The mechanism for generation of mean poloidal flow by turbulence is identified and elucidated. Flow generation link to the quasilinear radial current or the Reynolds stress. Poloidal acceleration will occur if the turbulence supports radially propagating waves and if radii gradients in the turbulent Reynolds stress and wave energy density flux are present. Poloidal flows can improve confinement regimes in fusion plasmas [7]. They can modify transport by impressing the turbulence. Several mechanisms have been proposed to explain the generation of sheared poloidal rotation in the plasma boundary region including ion orbit losses [8] and Reynolds stress [9]. To investigate the relation between turbulence and transport at the edge of plasma and the effect of Reynolds stress on suppression of turbulence, and to investigate the relation between poloidal flow and transport, we design and construct a new moveable Multi-purpose probe (Multi-purpose probe) in IR-T1 Tokamak. This paper is organized as follows. A description of the IR-T1 and the Multi-purpose probe is presented in Sec. 2; the results and discussion are presented in Sec. 3; and conclusions are given in Sec. 4.

1. EXPERIMENTAL SET-UP

The experiment has been performed on the IR-T1 which IR-T1 is a small research Tokamak located at the Plasma Physics Research Center. This Tokamak is an air-core tokamak without a copper shell. It has a major radius of R = 45 cm and a minor radius a = 12.5 cm, the plasma current I_p = 20…30 kA, the toroidal magnetic field B_t = 0.7…0.8 T, the average electron density n = (0.3…1.5) × 10^{19} m^{-3} and the electron temperature T_e = 200 eV. This device consists of a vacuum vessel with circular cross-section that was made from a stainless steel welding structure with two toroidal breaks and a minor radius b = 15 cm. The edge plasma parameters have been measured by a novel Multi-purpose probe (Multi-purpose probe). This probe can measure the electric and magnetic turbulence transport in the edge plasma, simultaneously. Also the poloidal flow can be measured by using this probe. Multi-purpose probe composed of three sections: electrical part, magnetic part and flow measurement section. The structure of these parts has been explained in the following subsections.

1.1. ELECTRICAL MEASUREMENT

The electrical part of Multi-purpose probe consists of four arrays. Each array has four tips which can be in the floating potential or ion saturation current state. Each tip has a diameter of 0.54 mm. In each array one tip is higher than other tips (Three tips of one array protrude 1mm above the state and one of them protrudes 2 mm). The tips have been made from tungsten rod that can bear high-temperature (Fig. 1). The radial electric field can be found by this part according to equation (1):

$$E_r = \frac{V_i - V_j}{dr}. \qquad (1)$$

E_r is the radial electric field, V_i and V_j are the floating potential, *dr* is the radial distance between two arbitrary tips which have been in the floating potential state. The poloidal electric field can be obtained from equation (2):

$$E_P = \frac{V_i' - V_j'}{dp}. \qquad (2)$$

Where E_p is poloidal electric field, V_i' and V_j' are floating potential and *dp* is the distance between two arbitrary tips which have located in two different poloidal positions. The radial and poloidal particle flux can be obtained from electric field according to equation (3) and (4):

$$\Gamma_r \approx \frac{nE_P}{B_T}\ , \qquad (3)$$

$$\Gamma_P \approx \frac{nE_r}{B_T}\ . \qquad (4)$$

In these relations Γ_r and Γ_p are the radial and poloidal particle flux. The density fluctuation is deduced from the ion saturation current. The Reynolds stress can be found by each electrical array according to equation (5):

$$R = < E_r E_p > / B_T{}^2. \qquad (5)$$

That *R* is the Reynolds stress and B_T is toroidal magnetic field. Also the radial profile of the electric field and Reynolds stress can be obtained by this part.

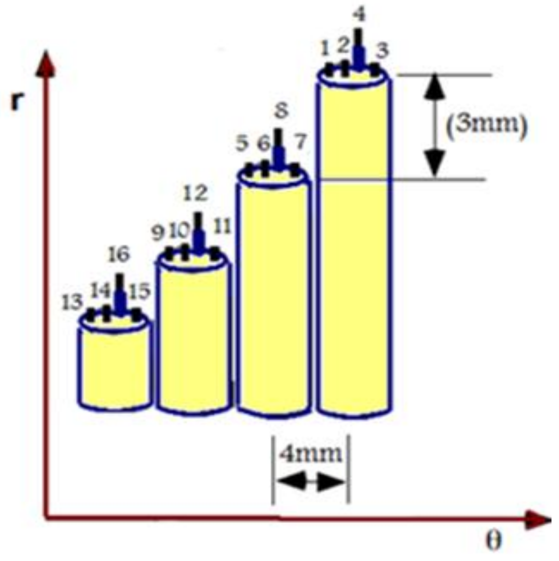

Fig. 1. Schematic diagram of the electrical part of Multi-purpose probe in IR-T1 Tokamak

1.2. FLOW VELOCITY MEASUREMENT

The direct measurements of flow velocities with a sufficient spatial resolution are highly desirable for better understanding of the reduction of the turbulent transport and the consequent formation of transport barriers [10]. In its simplest manifestation, the flow velocity can be measured by Mach probe [11, 12]. This probe consists of two tips separated by an insulator. The two tips measure the currents collected parallel and antiparallel to the magnetic field. The aim of done experiment is to understand the relation between the Reynolds stress and the flow velocity in poloidal direction and toroidal direction. So, the flow measurement part has been designed and constructed to measure the flow velocity in toroidal and poloidal directions. It is located behind the electrical part of the probe as shown in Fig. 2. It consists of 4 tips in which are in the ion saturation current state. Each tip has a diameter of 0.54 mm. They have been made from tungsten .The distance between two tips is 1 mm and the length of ceramic is 6 mm. The tips have to separate by an insulator. For this purpose, a ceramic with 4 apertures have been used. The sides of apertures have been prepared by filing as shown in Fig. 2. So the central part of ceramic acts as an isolator.

1.3. MAGNETIC MEASUREMENT PART

With this part, the fluctuation-induced Maxwell stress has been measured. The Maxwell stress has been calculated by equation (6):

$$< j \times B > = \frac{1}{\mu_0}\left(\frac{\partial}{\partial r} + \frac{2}{r}\right) < B_r B_\theta > . \qquad (6)$$

In which B_r is radial component of magnetic field and B_θ is poloidal component of magnetic field. The Magnetic measurement part consists of three coils. The radius of each coil is equal to 1.15 mm. The number of turns of coil is 80. The coils can measure total magnetic flux in three directions: radial, poloidal and toroidal direction. As shown in Fig. 3 the magnetic coils have been placed on the top of ceramic tube. A ceramic tube prevents from contact coils with plasma. During the experiments, tips 4, 8, 12 and 16 were used for measuring the ion saturation current while other tips measure floating potential.

2. DISCUSSION

The radial profile of measured floating potential by Multi-purpose probe is shown in Fig. 4. The results show that floating potential is maximum value in the Last Closed Flux Surface (LCFS). The curves of Fig. 4 show radial variations of floating potential in two different poloidal positions. The radial profile of radial electric field (E_r) and poloidal electric field (E_p) have been obtained from floating potential according to equation (1) and (2). As can be seen from Fig. 5,a, the radial electric field has been calculated about 180, 300 and 25 V/m in the SOL region, plasma edge and inside plasma, respectively. In this experiment, the poloidal electric field is about 50, 30 and 90 V/m in the SOL region, plasma edge and inside plasma, respectively.

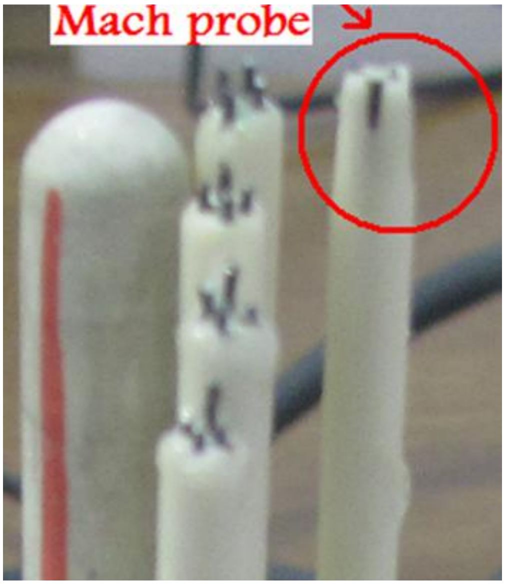

Fig.2. The scheme of Flow measurement part of Multi-purpose probe and its position in IR-T1 Tokamak

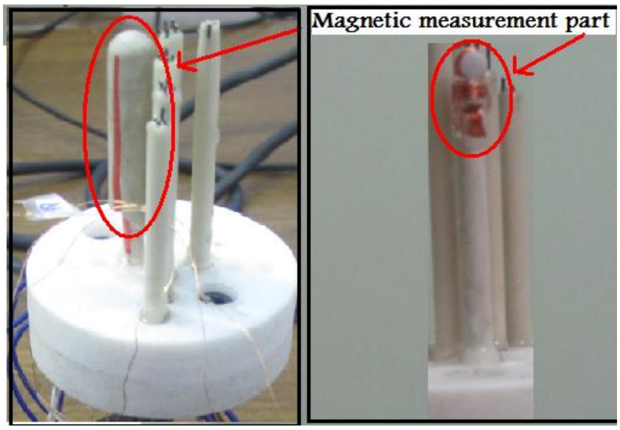

Fig. 3. The scheme of Magnetic measurement part of Multi-purpose probe and its position in IR-T1 Tokamak

As shown in Fig. 5, radial electric field has its maximum amount in the LCFS while poloidal electric field is minimum at this point. The results show that radial electric field will be negative inside the plasma. While the poloidal electric field increases inside the plasma. The particle flux can be obtained from electric field by the relations (3) and (4). The temporal evolution of particle flux at different radius has been calculated by Multi-purpose probe. The time evolution of radial and poloidal particle flux at different radius are shown in f Fig. 6. The results show that poloidal particle flux is maximum value in time period t=18 to 25 ms. It is limit that plasma current is flat. While time evolution of radial particle flux is minimum in this time period. It can be seen that the amount of poloidal particle flux at LCFS is higher than the amount of it at the other positions. This means that the radial transport is decreased around the LCFS. For understanding of the turbulence suppression reason in the plasma boundary region, the radial gradient of Reynolds stress has been measured.

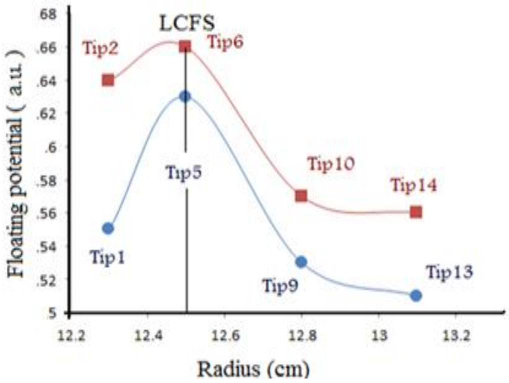

Fig. 4. The radial profile of floating potential measured by electrical part of Multi-purpose probe

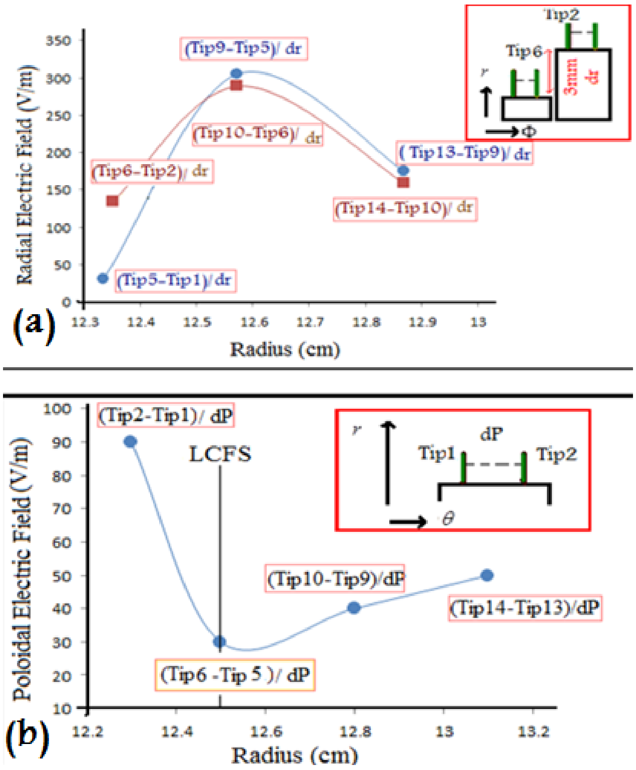

Fig. 5. The radial profile of (a) radial electric field and (b) Poloidal electric field measured by electrical part of Multi-purpose probe

Also Multi-purpose probe can measure time evaluation of Reynolds stress at different positions. So the relation between Reynolds stress and particle flux in different radius and different times can be clarified by Multi-purpose probe simultaneously. The radial profile of Reynolds stress is shown in Fig. 7. Its minimum value has been accrued at LCFS. The radial electric field and poloidal flow values have been changed in the vicinity of the LCFS. This means that Reynolds stress can suppress turbulence and modify turbulence transport. It can be concluded that decrease of the Reynolds stress to cause the remarkable increase in the poloidal particle flux. The radial gradient of Reynolds stress plays an important role in driving poloidal flows in the plasma boundary region. Decrease of radial particle flux and increase of poloidal particle flux in plasma edge improve the plasma confinement.

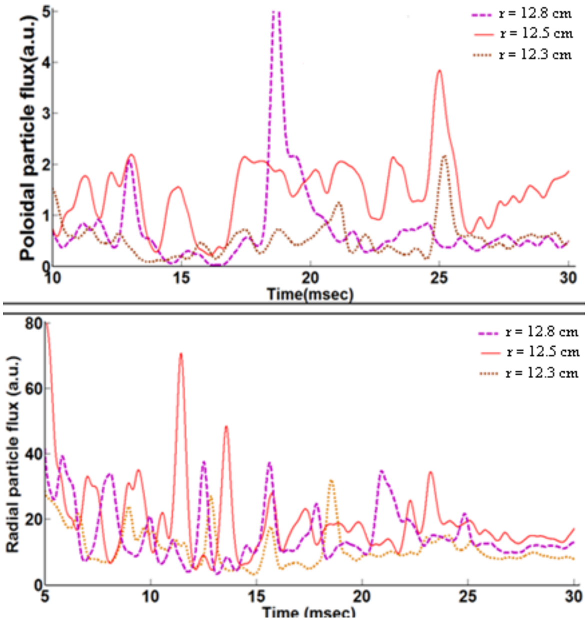

Fig. 6. The time evolution of (a) radial particle flux and (b) poloidal particle flux at different radius by electrical part of Multi-purpose probe

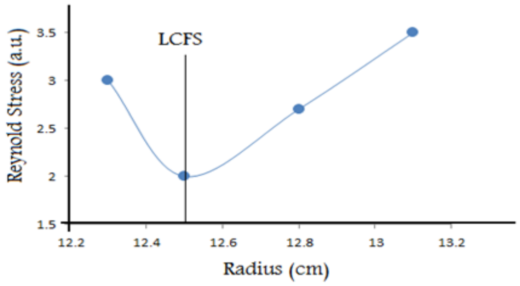

Fig. 7. The radial profile of measured Reynolds Stress by electrical part of Multi-purpose probe

CONCLUSIONS

In this paper, the first results of plasma parameters measurement by using the moveable Multi-purpose probe have been investigated and discussed. This probe has been installed in the IR-T1 Tokamak, recently. Multi-purpose probe can measure the electrostatic and magnetic fluctuation and flow velocity, simultaneously. It was found that the radial electric field has its maximum amount in the last Closed Flux Surface (LCFS) while poloidal electric field is minimum at this point. Also, the Reynolds stress is minimum at LCFS. With comparison between the radial profile of poloidal particle flux and Reynolds stress can be concluded that decrease the Reynolds stress cause to the remarkable increase of the poloidal particle flux. The radial gradient of Reynolds stress plays an important role in driving poloidal flows in the plasma boundary region. The radial electric field and poloidal flow values have been changed in the vicinity of the LCFS. This means that Reynolds stress can suppress turbulence and modify turbulence transport.

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РАЗРАБОТКА И ИЗГОТОВЛЕНИЕ НОВОГО ЗОНДА ДЛЯ ТОКАМАКА IR-T1

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Представлены и обсуждаются первые результаты, полученные с использованием подвижного многофункционального зонда (МФЗ), который был впервые установлен в камере токамака IR-T1. С помощью МФЗ можно одновременно проводить измерения флуктуаций электрического и магнитного полей в трех направлениях: полоидальном, радиальном и тороидальном. Зонд состоит из трех секций: электрической, магнитной и для измерения флуктуационных потоков. МФЗ имеет небольшие размеры и несильно возмущает плазму. С его помощью можно измерять соотношение между градиентом силы Рейнольдса и полоидальным потоком плазмы. Приводятся и обсуждаются данные о временном поведении и пространственных распределениях плазменного потенциала, силы Рейнольдса, величины полоидального плазменного потока, скорости потока, электростатических и магнитных колебаний. Из измерений следует, что вблизи крайней магнитной поверхности (LCFS) радиальное электрическое поле достигает максимума, тогда как полоидальное электрическое поле – своего минимума так же, как и сила Рейнольдса. Показано, что сила Рейнольдса вызывает существенный рост полоидального магнитного потока. Точно также в окрестности LCFS изменяются величины радиального электрического поля и полоидального потока. Из этого следует важный вывод, что сила Рейнольдса может подавлять турбулентность и обусловленный ею перенос.

РОЗРОБКА ТА ВИГОТОВЛЕННЯ НОВОГО ЗОНДА ДЛЯ ТОКАМАКА IR-T1

Mahmood Ghoranneviss, Sakineh Meshkani and Mansoureh Lafouti

Представлені і обговорюються перші результати, одержані з використанням рухомого багатофункціонального зонда (БФЗ), котрий був вперше встановлено в камері токамака IR-T1. За допомогою БФЗ можна одночасно проводити вимірювання флуктуацій електричного і магнітного полів у трьох напрямах: полоідальному, радіальному и тороідальному. Зонд складається з трьох секцій: електричної, магнітної та для вимірювання флуктуаційних потоків. БФЗ має невеликі розміри, та несильно збурює плазму. За його допомогою можна виміряти співвідношення між градієнтом сили Рейнольдса та полоідальним потоком плазми. Приводяться і обговорюються дані про часову поведінку та просторові розподілення плазмового потенціалу, сили Рейнольдса, величини полоїдального плазмового потоку, швидкості потоку, електростатичних і магнітних коливань. З вимірювань виходить, що поблизу крайньої магнітної поверхні (LCFS) радіальне електричне поле досягає максимуму, тоді як полоїдальне електричне поле – свого мінімуму так, як і сила Рейнольдса. Показано, що сила Рейнольдса спричиняє істотне зростання полоідального магнітного потоку. Так саме поблизу LCFS змінюються величини радіального електричного поля та полоїдального потоку. З цього зробимо важливий висновок, що сила Рейнольдса може подавляти турбулентність і обумовлений нею перенос.