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Development of the Microfission Chamber for Fusion Power Diagnostics on ITER

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A Microfission Chamber (MFC) provides time-resolved measurements of global neutron source strength and fusion power in ITER. An MFC to prevent any leakage of Argon gas, which the MFC contains, into the vacuum vessel has been designed. A stainless steel case encloses the MFC, and an exhaust tube detects any leaked Argon gas out of the vacuum vessel. MFCs will be installed behind blanket modules at upper and lower outboard position due to interface considerations with other equipment and the vacuum vessel. MFCs at the lower outboard position are located the center and to the rear of a blanket module, while MFCs at the upper outboard position are near the gap between blanket modules because of the narrow gap at that location between the modules and the vacuum vessel. The disparate effect of streaming neutrons on the response of MFCs at each installation location is analyzed through neutron transport calculation using MCNP version 5. Results indicate the linear combination of total responses of MFCs at the lower and upper outboard positions is insensitive to the changes in the position of the plasma while the ratio of streaming neutrons at the upper outboard position (~ 70 %) is higher than that detected at the lower outboard position (~ 20 %).

Keywords: ITER, ITER Diagnostics, Fusion Power Diagnostics, Neutron Measurement, Microfission Chamber, MCNP, Neutron Transport Analysis,

1. Introduction

The absolute measurement of neutron source strength is an important diagnostic in a burning plasma because fusion power can be derived directly from it. An in-vessel neutron monitor using microfission chambers (MFCs), pencil-sized gas counters containing fissile material (^{235}U) [1, 2], is a leading-candidate as a diagnostic tool to monitor neutron strength in ITER. Since a thick shielding blanket and the vacuum vessel stand between a conventional neutron monitor installed outside the vacuum vessel and the plasma, the MFC has the advantage of access and more accurate measurement of neutron strength. MFCs are filled with a 14 atm Argon (Ar) as an ionization gas. An airtight seal using Al_2O_3 prevents leakage of Ar gas at the point of connection to a signal cable. In fission reactors, the airtight seal has haven a track record of maintaining the airtightness during the operation. However, it is necessary to take steps to avoid Ar gas leakage from the MFC into vacuum vessel, in case the airtight seal are damaged by swelling [3] due to neutron irradiation, or strong shock due to disruption during ITER operations. Because, ITER requires that the allocated leak rate in vacuum vessel for all diagnostics system be than 10^{-8} Pam^3/s [4]. Here, an MFC to prevent Ar gas leakage into the vacuum vessel has been designed. In the present work [2], the installation position of MFCs behind blanket modules at both upper and lower outboard locations in the vacuum vessel has been proposed so as to render MFCs insensitive to changes in the position of the plasma. However, possible installation locations behind the blanket are limited to a narrow gap between the vacuum vessel and/or other equipment such as water manifolds and electrical straps. If MFCs are installed close to the gap between blanket modules, streaming neutrons may affect the functioning of the MFCs. In this work, installation locations have been determined so as not to interface with other equipment and the vacuum vessel. Further, the effect that streaming neutrons have on the response of MFCs depending on the installation location of the MFC, is estimated by a neutron Monte Carlo calculation using the Monte Carlo code for neutron and photon transport (MCNP) version 5 [5].

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2. Design of a Microfission Chamber to prevent gas leakage

2.1 Structure

The MFC is a pencil-sized gas counter containing ^{235}U, which was developed as an in-core monitor for fission reactors. In the MFC, a coating of UO_2 covers the outer cylindrical electrode. The active length is 76 mm, and the MFC contains a total amount of 10 mg of ^{235}U. The MFC is filled with 95% Ar and 5% N_2 gas at 14.6 atm. The housing material is stainless steel 316 L, and the electric insulator is alumina (Al_2O_3). A double coaxial mineral insulated (MI) cable is used to transfer signals

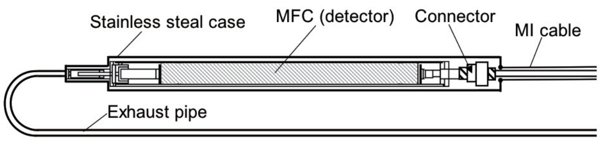

Fig.1 Schematic view of the MFC for preventing Argon gas leakage into the vacuum vessel.

and to supply power to the MFC. The cable uses SiO_2 as an electrical insulator with a packing density of 30%. The central conductor is also insulated with an SiO_2 insulator. An airtight seal using Al_2O_3 prevents leakage of Ar gas from the MFC at the point of connection to the MI cable. The measurement range of MFCs for high-power operations covers fusion power of 100 kW – 3 GW by using both counting and Campbelling (mean square voltage) [6] modes with a temporal resolution of 1 ms. This measurement range meets ITER requirements for a neutron monitor, which stipulate a range of fusion power from 100kW to 1.5 GW with a temporal resolution of 1 ms [7]. ITER also requires that a leak rate into the vacuum vessel from all diagnostics system be less than 10^{-8} Pam^3/s [4]. Therefore, it is necessary to take steps to avoid Ar gas leakage from the MFC into vacuum vessel, in case the airtight seal are damaged by swelling [3] due to neutron irradiation, or strong shock due to disruption during ITER operation. An MFC to prevent gas leakage has been designed. Figure 1 shows the schematic view of the newly designed MFC. In this design, the MFC is enclosed with in a stainless steel case. This prevents gas leakage into the vacuum vessel even if Ar gas leaks from the MFC due to insufficient airtightness of the seal. An exhaust pipe attached to the stainless steel case detects any leaked Ar gas. The structure of the connector part of the exhaust pipe is employed the same structure as that of the MI cable. Because acceleration test for mechanical shocks had been performed and no damage had been found for the MI cable [2]. Therefore, the connector part of the exhaust pipe can withstand mechanical shocks like disruption. About 1 atom of Ar gas is inserted between the core cable and the inner skin of the MI cable to maintain insulation resistance and to keep out moisture. The outer skin of the MI cable is welded to the stainless steel case.

2.2 Installation

MFCs will be installed behind blanket modules at both upper and lower outboard positions as shown in Fig.2 (a). Installation positions have been determined through Monte Carlo calculations using MCNP such that the average output of MFCs at the upper and lower outboard positions is insensitive to changes in the shape and position of the plasma [2]. At each proposed location, two MFCs and a dummy chamber with the same structure

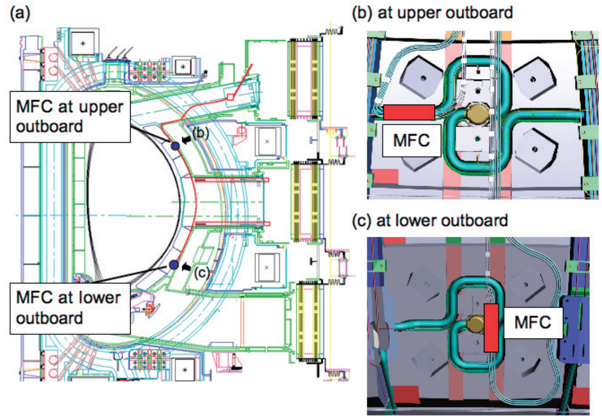

Fig.2 Location of MFCs on the ITER poloidal cross section (a) and schematic view of the installation position of MFCs at the upper outboard (b) and lower outboard (c) locations.

as an MFC but without any uranium coating on the electrode, will be installed. Two MFCs are installed at the same location so as to ensure that at least one remains operable over the course of ITER operations. The dummy chamber is also installed to compensate for the effect of gamma rays. In this design work, the installation location of MFCs behind blanket modules is determined by taking into account the interface with other equipment and the vacuum vessel. Figure 2 (b) and (c) shows a schematic view of the installation location of MFCs behind blanket modules at upper and lower outboard positions, respectively. At the lower outboard position, MFCs are positioned nearly in the center and to the rear of a blanket module. MFCs installed at the upper outboard position are located near the gap between blanket modules due to the narrow space between the blanket modules and the vacuum vessel. The newly designed MFC requires installation of both the MI cable (f ~ 6.35 m) and the exhaust pipe (f ~ 10.5 m). The MI cables and the exhaust pipes for both MFC positions are routed to the feedthrough in the upper port.

3 Effect of streaming neutrons on the MFC

The effect of the steaming neutrons on the MFC at the installation position is analyzed through neutron transport calculation MCNP, version 5 [5]. A 40° toroidal section which includes the first wall, the blanket modules, some filler modules, the vacuum vessel, each port (Upper, Equatorial, Lower), toroidal coils and poloidal coils are modeled in this calculation. However, this model does not allow for the potential effects of equipments located behind the blankets. The neutron source is a toroidally symmetric source with energy of 14 MeV and the neutron profile is set based on the main scenarios of ITER operations. As the detectors, cylinders with length of 76mm, corresponding to the active length of the MFC, are set at the designed installation locations. The spectra of neutrons incident to

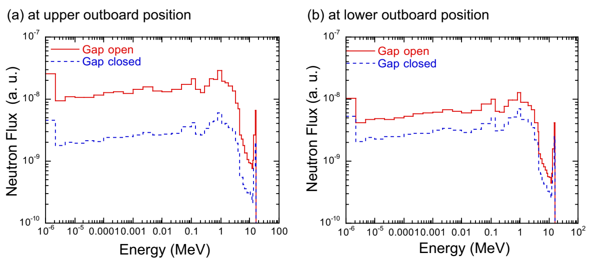

Fig.3 Neutron spectra at the installation positions for upper outboard (a) and lower outboard (b) locations. The solid and dotted lines designate spectra for open and plugged gaps, respectively.

the detectors are calculated. The solid line in Fig.3 (a) and (b) shows the neutron spectra of the MFC positions at upper and lower outboard, respectively. In this calculation, the neutron spectra are also estimated for a calculation model in which the gap around the blanket module where an MFC is installed, closed with materials used in the blanket module (SUS + water) in order to estimate the ratio of streaming neutrons at the installation position. The dotted lines 3 (a) and (b) show the neutron spectra at the upper and lower outboard positions in the gap closed model, respectively. It is believed that the difference between the neutron spectra with the gap either open or closed is due to neutrons streaming into the gap. The difference of the spectra at the upper outboard position is larger than that at the lower outboard position. As a result, the ratio of streaming neutrons to the total response of ^{235}U in the MFC are evaluated ~ 20 % and ~ 70 % at lower and upper outboard positions, respectively. The ratio of streaming neutrons to total response of the MFC at the upper outboard position is higher than that at the lower outboard position because upper outboard MFCs are installed closer to the gap than those at the lower outboard position. As described in Sec.2.2, present installation positions have been determined so as to be insensitive to changes in the position of the plasma. However, if the ratio of streaming neutrons varies significantly by virtue of the installation positions of the MFC, then a precise, absolute measurement of neutron source strength may not be assured. Streaming neutrons may influence a response of MFCs responses because the cross-section of ^{235}U has a strong dependence upon neutron energy. Therefore, variation in the ratio of streaming neutrons for the response of MFCs due to changes in the plasma position is calculated. Variations in the ratio of streaming neutrons due to vertical and horizontal plasma shifts are shown in Fig.4 (a) and (b) respectively. The ratios for the response of MFCs at upper and outer outboard position are almost the same (within 5 %), even as the plasma position changes. This absence of effect is considered to be due to the installation of the MFCs in locations not directly exposed to the plasma. Fig.4 (c) and (d) show variations in total

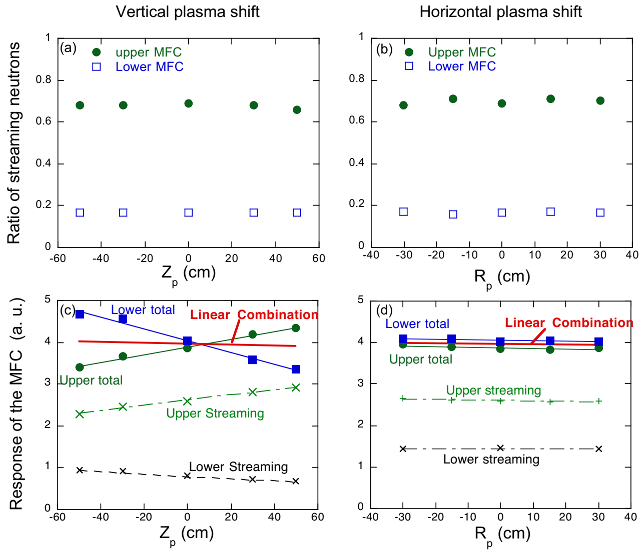

Fig.4 Variation in the ratio of streaming neutrons to total response of the MFCs for a vertical plasma shift (a) and the horizontal plasma shift (b). Variation in total response, the response due to streaming neutrons at MFC at the upper and lower outboard position and the linear combination of the responses of the MFCs at both positions for for a vertical plasma shift (c) and the horizontal plasma shift (d).

responses and response due to streaming neutrons of the MFC for vertical and horizontal plasma shifts, respectively. The response due to streaming neutrons as well as total response of the MFC at the upper outboard position increases as the plasma shifts vertically, while both the response due to streaming neutrons and total response of the MFC at the lower outboard position decrease for vertical shift of the plasma position as shown in Fig.4 (c). However, the linear combination of the MFCs at the upper and lower outboard position varies little (~ 4%) for vertical shift of the plasma position. The linear combination for the horizontal shift of the plasma potion also varies little (~ 3%) as shown in Fig.4 (d). This results suggest that the linear combination of MFCs at the installation positions described in Fig.2 (b) and (c) is insensitive to the changes in position of the plasma even if the ratios of streaming neutrons are different between at the upper outboard and the lower outboard position.

Summary

In this work, an MFC to prevent leakage of Ar gas into the vacuum vessel is described. A stainless steel case covers the MFC and an exhaust tube detects leaked Argon gas. About 1 atm of Ar gas is injected between the core cable and the inner skin of the MI cable to maintain insulated resistance and to keep out moisture. Installation positions of MFCs behind blanket modules at upper and lower outboard positions have been determined by taking into account the interface with other equipment and the vacuum vessel. MFCs at the lower outboard position are located nearly in the center and to the rear of the blanket module, while MFCs at the upper outboard position are located near the gap between blanket modules due to the narrow space between the modules and the vacuum vessel. The effect of streaming neutrons on the MFCs at each installation position is analyzed through neutron transport calculation MCNP, version 5. Results indicate that the ratio of streaming neutrons hardly varied due to changes in the plasma position, while the ratio for MFCs at the upper outboard position (~ 70 %) is higher than that at the lower outboard position (~ 20 %). Further, the calculation results indicate the linear combination of the responses of the MFCs at the lower and upper outboard positions is insensitive to the changes in the position of the plasma.

In the present work, The MCNP model used for this study did not include the effect of equipment that may be installed near the MFCs, i.e., water cooling pipes. Future research in this area will include a detailed model of the effect of this upon MFC measurements of neutron source strength in ITER.

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