Development of in-vessel components of the microfission chamber for ITER^{a)}

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Microfission chambers (MFCs) will measure the total neutron source strength in ITER. The MFCs will be installed behind blanket modules in the vacuum vessel (VV). Triaxial mineral insulated (MI) cables will carry signals from the MFCs. The joint connecting triaxial MI cables in the VV must be considered because the MFCs and the MI cables will be installed separately at different times. Vacuum tight triaxial connector of the MI cable has been designed and a prototype has been constructed. Performance tests indicate that the connector can be applied to the ITER environment. A small bending-radius test of the MI cable indicates no observed damage at a curvature radius of 100 mm. © 2010 American Institute of Physics. [doi:10.1063/1.3485080]

I. INTRODUCTION

The absolute measurement of the neutron source strength is an important diagnostic in a burning plasma because fusion power can be derived directly from the neutron source strength. Microfission chambers (MFCs),^{1,2} a pencil-size gas counter containing fission material (²³⁵U), are one of the most important diagnostic tools for measuring total neutron source strength in ITER. Because a MFC can be installed in the vacuum vessel (VV), it can measure neutron source strength without any effects from the thick VV and heating systems. The MFCs will be installed behind blanket modules in the upper and lower outboard regions of the VV in ITER.² Triaxial mineral insulated (MI) cables will carry signals from the MFCs to the upper port and will be connected to a soft cable outside the VV. The MFC for ITER has been developed on the basis of the in-core monitor for fission reactors.

A MFC formulated to prevent gas leakage has been designed to apply to ITER vacuum conditions,³ so far. However, some issues remain before the MFC may be installed in ITER. For example, the MFC and the MI cable have been used as a unit in fission reactors. However, in ITER the MFC and the MI cable are scheduled to be installed separately. The MI cable will be installed during the tokamak assembly phase before the installation of other equipment in the VV. On the other hand, the MFCs (²³⁵U included) are planned to be installed in the tokamak after the first plasma operation for reasons of safety. Therefore, the MFC will be connected to the MI cable in the VV. Another issue related to installation concerns the bending of the MI cable. The MI cable has been used with a curvature radius (R) of >1000 mm in fission reactors. However, due to the variety of equipment and

diagnostic components that will be installed in the ITER VV, the MI cable will be installed with a smaller curvature radius of 100–200 mm. This paper reports the results of the development of in-vessel components of the MFC and the MI cable. A joint for connecting the MI cables in the VV has been designed, and a prototype was constructed. A small bending-radius test of the MI cable was conducted to assess the cable's operational performance when bent into a small curvature radius.

II. OUTLINE OF THE MICROFISSION CHAMBER

A. Structure

Figure 1(a) shows a schematic view of a typical MFC. In the MFC, a coating of UO₂ covers the outer cylindrical electrode. The active length is 76 mm. A total amount of 10 mg

FIG. 1. (a) Schematic view of the typical MFC, (b) the MFC designed for preventing argon gas leakage (Ref. 3), and (c) the structure of the MI cable.

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FIG. 2. (Color online) Schematic view of the vacuum tight triaxial connector of the MI cable, (a) the external appearance, (b) the inner structure, and (c) the inner structure of the core region.

of ^{235}U is used. The MFC is filled with argon (Ar) gas at 14.6 atm which serves as the ionization gas. The housing material is made of stainless steel 304 L, and the electric insulator is made of alumina (Al_2O_3). Figure 1(b) shows a drawing of the MFC designed to fulfill the requirements of the VV environment of ITER. This modified MFC is enclosed in a stainless steel case. The case prevents gas leakage into the VV in the event that Ar gas leaks from the MFC due to an insufficient airtightness of the seal. An exhaust pipe attached to the stainless steel case is designed to detect a gas leak and vent the gas outside the VV. The structure of the triaxial MI cable is shown in Fig. 1(c). Cu is used as the core. SiO_2 is used as an electric insulator both between the core and inner sheath and between the inner sheath and the outer sheath. Ar gas fills the inner sheath to prevent any discharge between the core and the inner sheath.

B. Installation

The MFCs will be installed between the VV and blanket modules at both upper and lower outboard positions. Monte Carlo calculations using a general Monte Carlo N -particle transport code (MCNP)⁴ reveal that the linear combination of outputs of the MFCs in the upper and lower outboard positions is insensitive to changes in the shape and position of the plasma.^{2,3} At each proposed location, a set of MFCs (two MFCs and a dummy chamber, which has the same structure as the MFC, except no uranium coating on the electrode) will be installed. Two MFCs are installed at the same locations as redundancy. The dummy chamber is installed to compensate for the effect of gamma rays. The MI cables of the MFCs at

the upper and lower positions are routed to the upper port and connected to the soft cable at the feedthrough in the upper port. The lengths of the MI cable for the upper and the lower MFCs are about 5 and 12 m, respectively. Current plans for installing the MFC into the VV call for the MFC and the MI cable to be installed at different times. Since the MFC contains fission material (^{235}U), it should be installed in the tokamak after first plasma operations from the point of view of safety. On the other hand, the MI cable is scheduled to be installed early in the process of assembling the tokamak in order to route the MI cable under the water manifold and to avoid interface conflicts with other in-vessel components.

III. DEVELOPMENT OF THE IN-VESSEL CONNECTOR FOR THE TRIAXIAL MI CABLE

A. Design of connector of the MI cable

In order to install the MFC and the MI cable at different times, a joint for connecting them in the VV is necessary. Although the MFC and the MI cable have been used as a unit in fission reactors, adapting them for use in the ITER environment requires the design of a joint to connect the MI cables. Connecting them in the VV requires that the outer sheath of the joint remain vacuum tight to prevent any gas leakage from the MI cable into the VV. In addition, the diameter ϕ of the joint has to be less than 20 mm because the space between the VV and the blanket module is only ~ 25 mm. Consistent with these constraints, we have designed the connector of the MI cables as shown in Fig. 2. As shown in Fig. 2(a), the diameter and length of the newly designed connector are 16.4 and 270 mm, respectively. This diameter is enough small to install it between the VV and blanket modules. The inner structure of the connector is shown in Figs. 2(b) and 2(c). The core is connected by resistance spot welding using Ni-foil, which has a good track record in neutron detectors for fission reactors. Ceramic shields are inserted as insulators to avoid any contact of the Ni-foil with the inner sheath as well as to avoid any contact between the inner sheath and the outer sheath.

Figure 3 shows the process for connecting the triaxial MI cables. First, the connecting pipes of the inner sheath and the outer sheath are prepared. The core is then connected by resistance spot welding using Ni-foil [Fig. 3(a)]. Next, the ceramic shields are inserted between the core and the inner sheath [Fig. 3(b)] and the connecting pipes for the inner sheath are guided to the connecting point and joined [Fig. 3(c)]. Finally, the ceramic shields are inserted between the

FIG. 3. (Color online) Process for connecting the MI cable: (a) the connecting pipes of the inner sheath and the outer sheath are prepared and the core is connected, (b) ceramic shields are inserted between the core and the inner sheath, (c) the connecting pipes for the inner sheath are guided to the connecting point and connected, (d) ceramic shields are inserted between the inner and the outer sheath, and (e) the connecting pipes for the outer sheath are connected.

FIG. 4. (Color online) The jig for the bending test of the MI cable.

inner and the outer sheath [Fig. 3(d)] and the connecting pipes for the outer sheath are joined [Fig. 3(e)].

B. Performance tests of the prototype connector

A prototype of the connector of the MI cable was fabricated to assess its feasibility. As described in Sec. III A, the core of the MI cable on both ends (the detector side and the feedthrough side) are connected via Ni-foil. Since the size of the inner sheath and material changes at the joint, impedance also changes. There is a possibility that signals from the detector would be reflected and attenuated at the joint due to a change in impedance. As such, a signal transmission test was conducted using the prototype. Results indicate that attenuation of the input signal is only $\sim 3\%$ with negligible reflection of the signal. This finding indicates that the connection has no negative effect on signal transmission. The prototype of the MI cable connector also was tested for vacuum leaks at room temperature to check the airtight character of the joint. We confirmed that the helium leak rate was less than the detection limit, 1×10^{-10} Pa m³/s. In the withstand voltage test, it was confirmed that withstand voltage is over 1 kV, which is five times the operating voltage (200 V). These results indicate that the connector can be applied to ITER.

IV. SMALL BENDING-RADIUS TEST OF THE MI CABLE

A. Outline of the test

In the present design for installing the MI cable into the VV, the minimum curvature radius is 120 mm at the opening of the upper port. However, since the MI cable usually is used in straight-line segments ($R > 1000$ mm), there is a possibility that bending the MI cable to a small curvature radius of 120 mm might result in the core breaking or leakage of Ar gas due to a fracture of the inner sheath. Performance tests of the MI cable after bending the MI cable to small curvature radius were conducted to check the suitability of the cable for installation into the VV in ITER.

B. Results

In order to bend the MI cable to a predetermined curvature radius, we prepared a bending jig as shown in Fig. 4. Using the jig, the MI cable may be bent at $R=400$, 300, 200, and 100 mm. Figure 5 shows the result of the bending the MI cable. The MI cable was placed in the jig and bent at $R=100$ mm.

FIG. 5. (Color online) The MI cable bent at $R=100$ mm.

After bending the MI cable, several tests were conducted to check operational performance. The possibility of the damage of the inner sheath was checked with a helium leak test. Results indicate that the helium leak rate was less than the detection limit, 1×10^{-10} Pa m³/s, and that break of the inner sheath was not identified. In order to check for a break in the core and a short between the core and the inner sheath, a continuity test and insulation resistance test were conducted. Results indicate neither break nor short circuit in the core, thereby confirming the electrical soundness of the bent MI cable.

Thus, in the performance tests after bending the MI cable, no damage was observed at $R=100$ mm. In the future, we will conduct a thermal test to investigate the combined effects of thermal expansion and bending of the MI cable.

V. FUTURE WORK

This work focuses on the development of the in-vessel components of the MFC for installation into the VV. During ITER operations, the MFC and the MI cable will be subject to electromagnetic forces as a result of disruptions and vertical displacement events in the plasma. The temperature of the MFC and the MI cable will rise due to both nuclear heating and convection. In the future, in order to ensure the full capabilities of the MFC and the MI cable during ITER operations, it is necessary to conduct electromagnetic analysis and thermal analysis based on neutronic analysis.

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