Electromagnetic analysis for the in-vessel transfer lines of neutron activation system

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HIGHLIGHTS
- The electromagnetic (EM) load on the in-vessel transfer line of ITER neutron activation system is calculated.
- The EM load is caused mainly by creating a big eddy current loop together with the vacuum vessel.
- It is shown that electric insulation of the transfer line from the vacuum vessel can reduce the EM load drastically.

ARTICLE INFO

Article history:
Received 25 September 2016
Received in revised form 8 March 2017
Accepted 9 March 2017
Available online xxx

Keywords:
ITER
Neutron activation system
Electromagnetic load
In-vessel transfer line

ABSTRACT

Neutron activation system is one of the neutron diagnostic systems in ITER which measures total neutron flux and first wall neutron fluence. This system has several pneumatic tubes installed on the vacuum vessel to deploy the irradiation samples near the plasma. The pneumatic tubes, called as transfer lines, get eddy current induced during plasma disruption, leading to Lorentz force by interacting the background magnetic field. This paper presents the electromagnetic (EM) loads on the in-vessel components of NAS for various disruption scenarios. The EM loads were calculated with the finite element solver, ANSYS-EMAG. It is proposed that the transfer lines are electrically insulated from the vacuum vessel in order to mitigate the excessively high EM loads. The analysis results showed that the electrical insulation reduces the load by one order of magnitude.

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1. Introduction

Neutron activation system (NAS) [1] is one of the neutron diagnostic systems in ITER, which is a nuclear fusion device (Nuclear Facility INB-174) under construction in France. NAS measures total neutron flux and first wall neutron fluence by irradiating foil samples with neutrons near a plasma and then counting the decay gamma from the activated sample after retrieving them from the machine. The foil sample is contained in a capsule and transferred to an irradiation station (IS), where the sample is irradiated by neutrons. The capsule transfer is made in a pneumatic way along the tubes installed on the vacuum vessel (VV) wall [2]. The tubes, called as transfer lines, are fixed to the VV wall with many clamps. As the tubes and clamps are a passive conductor made of stainless steel, they will be loaded with electromagnetic (EM) force due to current induced during plasma disruption.

In this paper the EM loads on the NAS transfer lines are calculated by taking into account three different types of current origin: poloidal flux variation, toroidal flux variation and halo current [3]. The EM analysis approach is described in Section 2. The results on EM loads are analyzed and discussed in Section 3. The design to reduce the EM loads of the transfer line is proposed as well. The conclusion is made in Section 4 with a brief summary.

2. EM analysis approach for NAS transfer lines

NAS has ten irradiation stations installed on the vacuum vessel. Four of them are shown in Fig. 1. Each irradiation station is connected with two transfer lines which are made of a stainless steel (SS) tube of 12 mm outer diameter and 1.5 mm thickness. All the transfer lines are fixed with SS clamps whose base is welded on the VV wall and the clamps are placed with the distance interval of approximately 0.2 m. They are routed in the poloidal direction and...
collected at the lower port to penetrate the vacuum boundary of the vacuum vessel.

EM loads on the NAS irradiation stations and transfer lines are calculated with the finite element (FE) numerical simulation by using ANSYS-EMAG [4]. Fig. 2 shows the FE model of 40-degree sector of the ITER machine including the vacuum vessel, all the magnets (TF/CS/PF coils) and the NAS components. To simplify the model, the in-vessel components such as blankets and divertors are not included. Removal of the in-vessel component will result in more conservative EM load on the NAS transfer lines because EM shielding of the in-vessel components will not be taken into account in the analysis. Anyway, as the in-vessel components have spatial gaps each other, the shielding effect will not be significant for the NAS transfer lines which can be considered as a part of VV from the electrical point of view. It is confirmed from an independent analysis that the shielding effect of the in-vessel components on the eddy current induced on VV is less than 5%. The transfer line is modelled with solid volume of rectangular cross-section (8 mm × 8 mm) in order to mitigate the modeling complexity and save the computation memory.

Three different types of current origins due to plasma disruption are taken into account: (1) the poloidal flux variation (PFV) by the plasma current decay, (2) the toroidal flux variation (TFV) during the thermal quench and (3) the halo current. To impose PFV in the EM analysis, the plasma current calculated from the plasma equilibrium simulator (DINA) is directly converted and applied to the FE model of ANSYS-EMAG with the methodology proposed in Ref. [5]. To simulate TFV in the EM analysis model, the poloidal plasma current change equivalent to the TFV is applied. Fig. 3 shows that this approach reproduces exactly the same TFV as the input data from DINA. The halo current is applied with a source/sink model. The positions of the current source and sink are assumed on the inboard and outboard region of the lower part of the VV wall, as shown in Fig. 4. According to Ref. [3], the inflow halo current follows two current paths: the divertor and the VV wall. As the divertor is not included in this analysis model, some fraction of the total halo current (33%) is given directly on the VV wall as the source and sink.

All the TF/PF/CS coils are excited in the analysis to generate the background magnetic field. The periodic boundary condition is applied to both sides of the 40-degree model and the axisymmetric condition is applied to the central axis of the machine. The far-field boundary is simulated with the element type INFIN 111 provided in ANSYS-EMAG. The elements are shown at the outer skin of the model in green color at the left of Fig. 2.

The electrical resistivity applied for the vacuum vessel and the NAS components is 8.0e-7 [Ωm].

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**Fig. 1.** Irradiation stations and transfer lines of NAS installed on the ITER vacuum vessel.

**Fig. 2.** FE model for EM analysis, including NAS, VV and TF/CS/PF coils; a zoom-in view for part of NAS FE model is shown at the top corner.

**Fig. 3.** Comparison of toroidal flux variation during MD DW L36 between DINA and ANSYS model.

**Fig. 4.** Halo current flowing on VV during MD DW 36.
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