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Detailed electromagnetic analysis for design optimization of a tungsten divertor plate for JET

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Abstract

The ITER-like Wall Project (ILW) at JET aims at replacing carbon fiber composite (CFC) on plasma-facing surfaces by tungsten and beryllium, which are relevant to the ITER design. The original design of the JET divertor, with CFC tiles, has quite high eddy current-related loads. Tungsten has a much higher electrical conductivity than CFC, and this does not allow a simple replacement of the CFC with solid tungsten in the original design.

So-called fishbone- or tree-like shapes, avoiding large loops of eddy currents, have been proposed for the tungsten components and supporting structures. These shapes reduce the eddy current loads drastically and provide well-defined paths for the Halo current.

This report describes how the design of the supporting structures is driven by electromagnetic considerations. Analytical and numerical techniques are combined and cross-checked. A study has undertaken for two variable orthogonal magnetic fields, for two cases of Halo current, with three orthogonal background magnetic fields. Then the worst load combinations were identified and used for the calculation of the forces and stresses in fixtures.

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Keywords: Bulk tungsten; Divertor; ITER-like Wall; Lamellae; Eddy currents; Halo; Loads; Fixtures

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1. Introduction—design description for presently used and newly developed JET divertor

The ITER-like Wall Project (ILW) at JET [1,2] aims at replacing the carbon fiber composite (CFC) on plasma-facing surfaces by tungsten (W) and beryllium (Be), which are relevant to the ITER design. One of the R&D projects in the ILW Project is to develop bulk W components as a replacement for the CFC load-bearing septum replacement plates (LB-SRP) [3,4].

The centrally located part of the original JET divertor consists of 48 "load-bearing septum replacement plates" (LB-SRP). Each includes two large CFC tiles (250 mm × 170 mm × 40 mm) and two small CFC tiles (160 mm × 85 mm × 25 mm). The tiles are attached on two superimposed Inconel frames. Electromagnetic (EM) analysis for the original design has shown that it can accommodate just marginally the eddy current-related loads. Tungsten has relatively high electrical conductivity, exceeding that of CFC by about two orders of magnitude (at 80 °C, taken as design input), and this does not allow the principle of the original design to be kept with a simple replacement of the CFC by solid tungsten. Instead a total redesign of the LB-SRP including the supporting structures has been necessary. This has increased significantly the overall R&D effort.

A solution has been proposed to employ an assembly of thin (6 mm × 60 mm × 40 mm) W lamellae on a fishbone-shaped supporting structure, which excludes large contours of eddy currents and provides well-defined Halo current paths (see Fig. 1) [5,6].

The detailed features of the design are summarized below:

- All lamellae are grouped in pairs, which are separated by insulated spacers.
- Within each pair, two lamellae are interconnected by non-insulated T-shaped spacer.
- T-spacers are used for attachment and for providing a path for the Halo current.
- Lamellae with spacers are assembled in eight stacks, about 170 mm × 60 mm × 40 mm each.
- Each stack is compressed by two tie rods with sufficient elastic properties.
- Each stack is attached to a beam. All beams are elongated toroidally and called wings.
- All eight wings are integral with a middle part, elongated in the radial direction.
- Each wing has a foot stepping on a base plate and providing a path for the Halo current.
- Two additional shorter wings are located under two top wings for structural purposes.
- The middle part, all wings and feet, are made as a monolithic Inconel piece, called a wedge.
- The adaptor locates between the wedge and the base plate and has a cross-like shape.

This paper presents major results of the transient electromagnetic (EM) analysis aimed at optimizing the design of the JET divertor with solid tungsten components.

2. Calculation technique and task definition

This paper presents results obtained with a combined use of numeric and analytic techniques. Practical calculations were done with well-known formulas for a "resistive pattern" of eddy currents in rectangular bricks or lanes. For example, each pair of lamellae with T-spacer was split in three rectangular zones, with different formulas used for each zone and for each orthogonal vector of a variable magnetic field. Coefficients in the formulas were adjusted with use of numeric solutions for essential elements such as one pair of lamellae or one wing, etc.

Described combination of two techniques has proven to be effective. It formed a basis for a new design with the fishbone shape for the wedge and the cross-like shape for the adapter, and allowed specify necessary pre-tension forces. These shapes and forces were supplied as input for ANSYS simulations, which were performed by other authors [7]. Sum EM loads were cross-checked.

The following currents and load components were accounted, and sum forces found:

- Eddy currents induced by the variation of radial and vertical magnetic fields, 100 T/s each (this value had came from JET disruptions database and suggested as input by JET team).
- Global toroidal eddy current (Fig. 4), induced by the variation of the poloidal magnetic flux.