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Thermal analyses of the mm-waveguide cooling concepts for the ITER electron cyclotron upper launcher first confinement system

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HIGHLIGHTS

- Presentation of two variants of a novel high-power waveguide cooling design.
- Fluid dynamic simulation at nominal ECH power transmission.
- Transient analysis of a typical ITER thermal cycle.
- Manufacturing and assembly concept for the waveguide cooling channels.

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ABSTRACT

The ITER Electron Cyclotron Heating Upper Launcher (ECHUL) will be used to drive current locally inside magnetic islands located at the q = 2 (or smaller) rational surfaces in order to stabilize neoclassical tearing modes (NTMs). Each antenna consists of eight beam lines that are designed for the transmission of up to 1.5 MW of mm- wave power at 170 GHz, with at least 90% of the power in the main HE11 mode.

Mm-wave power is assumed to be converted into heat by ohmic dissipation in the waveguide, with intensity peaks reaching up to 9000 W/m^2, consequently to enable continuous working operation at nominal transmitted power, temperature control of the waveguide is required via an active cooling system.

Available commercial solutions for the cooled waveguide are incompatible with the FCS, which will be subject to higher heat fluxes and shall comply with ITER SIC-1 requirements. Therefore a dedicated cooling system must be designed. This study presents the results of the thermal mechanical analyses of two different cooling concepts, and concludes the most suitable concept for the final Upper Launcher FCS system design.

1. Introduction

Each of the fours antennas consists of eight beam lines that are designed for the transmission of up to 1.5 MW of mm-wave power at 170 GHz (30.000 thermal cycles with pulse durations from 400 to 3600 s [1]), estimated losses are considered additive and mm-wave power is assumed to be converted into heat by ohmic dissipation in the waveguide, with intensity peaks reaching up to 9000 W/m^2 (Fig. 1).

The UHV transmission lines in the FCS (First confinement system), for which SIC-1 classification requirements apply, consists of a Z shaped set of straight corrugated aluminum alloy (EN AW-6061) waveguides (WG), totaling 12.8 m, connected by miter bends with a nominal inner diameter of 50 mm (Fig. 1).

For continuous working operation at nominal transmitted power, temperature control of the waveguide is required via an active water cooling system. Available commercial solutions for the waveguide are incompatible with the FCS, which will be subject to higher heat fluxes and must comply with ITER SIC-1 [2] requirements. SIC-1, is the highest safety importance class, which consists of all components that are necessary maintain ITER in a safe state. Therefore a dedicated cooling system must be designed.

Following the design and analysis evolution of several cooling concepts, this study presents the results for the cooling system deemed most suitable for the final FCS system design.

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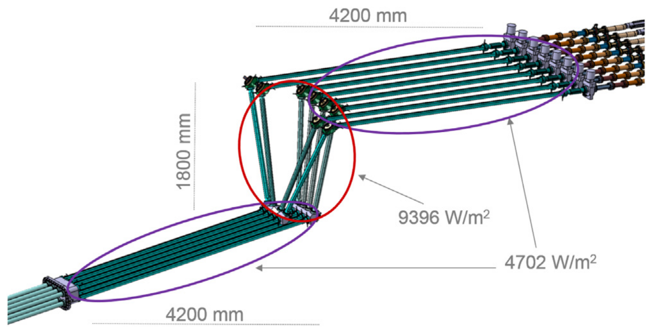

Fig. 1. FCS WG layout and average heat flux per section.

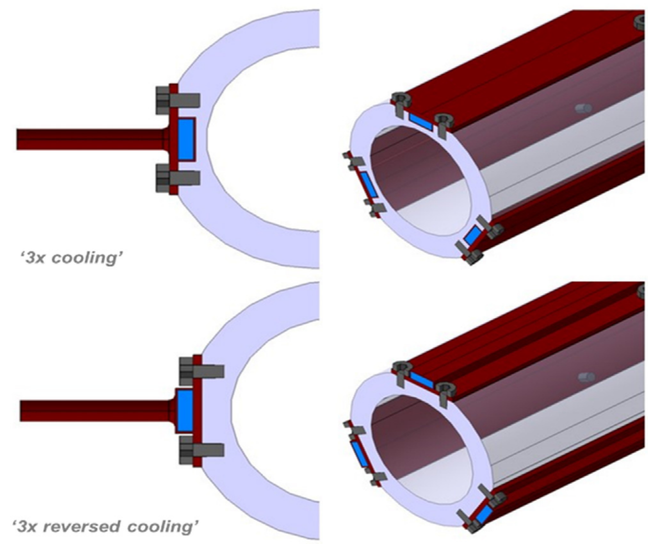

Fig. 2. EPFL-SPC FCS WG cooling concept cross-section comparison.

2. Design drivers

In addition to the ohmic losses related to the cyclic mm-wave transmission, the waveguides of the FCS shall be capable of resisting the applied external loads and displacements during thermal excursions (room to baking temperatures), plasma disruptions and seismic events.

It was opted to manufacture the waveguides in aluminum 6061-T6 [3], which has several advantages (lower elastic modulus than SS, high electrical conductivity and relative low mass), however it also poses the following challenges:

- Annealing of Aluminum begins at low temperature;
- After 10000 h at 130 °C, aluminum can lose ∼20% of its Yield strength;
- The only cooling medium permitted in the ITER upper launcher is water provided from the CCWS (component cooling water system) [4], which allows a maximum outlet temperature of 80 °C. In addition, ITER design rules do not permit direct water-aluminum contact for SIC-1 components.

Based on the listed parameters the waveguide cooling system shall be designed to assure a maximum operating temperature of 80 °C.

Albeit that the cooling requirements vary with the loads in each section of the FCS system, the adopted waveguide cooling system shall be the same for the entire FCS, and therefore designed for the most conservative values of heat flux, water inlet temperature and flow rate.

3. Design description

Resulting from the iterative design & analysis of several cooling concepts, the EPFL-SPC WG cooling concept is based on applying 'integrated' cooling channel(s) along the length of the WG (Fig. 3).

The initial proposition, named '3x cooling' (Fig. 2), was to machine a gorge along the waveguide length and then attach via fixation screws a cooper cooling channel.

The second proposition, named '3x reversed cooling' (Fig. 2), is a slight modification in relation to the previous concept with the intent of simplifying both the manufacturing and assembly processes. Instead of machining a gorge into the waveguide, a flat slit would provide the contact between the WG and the cooling channel. Which in-turn would also increase the thermal contact surface in relation to the previous cooling concepts.

Both concepts follow the same principles:

- The cooling channel should be: (a) as small as possible to reduce manufacturing constraints; (b) minimize necessary WG thickness; (c) not alter the WG stiffness; (d) be compatible with the flanged coupling; (e) compatibility as much as possible with standard off the shelf components; (f) reduce number of manufacturing procedures.
- In order to optimize the cooling efficiency, the cooling channel would be made of a rectangular copper tube (11 × 3.5 mm, 2 mm thickness), brazed to a fixation plate, which would increase the thermal contact surface between the WG and the cooling channel, in relation to a circular channel of equivalent cross-section area.
- Both concepts would ensure the structural minimum thickness of the waveguide in all areas, calculated according to the ASME design code [5] to be 2.5 mm.

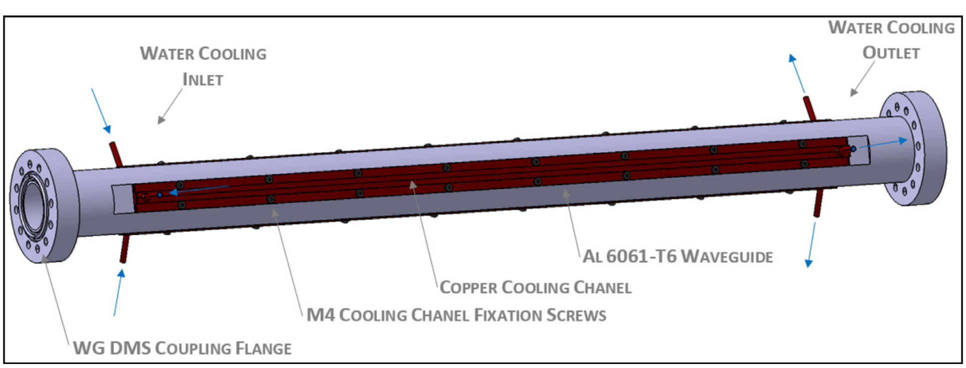

Fig. 3. EPFL-SPC FCS WG cooling concept.

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