Abstract
Four positions of the ITER upper port configuration are foreseen to accommodate the EC wave launching system for stabilising the Neoclassical Tearing Modes (NTM) at the q=3/2 and 2/1 magnetic flux surfaces by localised current drive (CD). The Upper Launchers are further proposed to access the q=1 region to provide control of the sawtooth period and amplitude and thus to inhibit a major NTM trigger. The current reference design, the “Extended Performance front steering Launcher” or EPL, offers this functionality by a mm-wave system that covers the plasma radii $\rho_p$ of 0.4 - 0.9. The mm-wave system is integrated into the structural system which is achieved by adapting the shielding and cooling configuration of the blanket shield module as the front part to the plasma and of the internal neutron shield in the main structure. The evolving manufacturing concepts striving for communality with diagnostics plugs have led to a slim wall design for the main structure. It is characterised by a passively cooled single wall section forming the central part intermediate to the actively cooled double wall sections at the front and back end. The thermal analysis of the baking concept proves that the baking temperature of the port plug can be kept above 200°C.

1. Introduction
The EC wave launching system at the upper port level of ITER is developed under EFDA by the “ECHULA group” of EU associations (ENEA/CNR Milano, CRPP Lausanne, FOM Rijnhuizen, FZK Karlsruhe, IPP/IPF Garching/Stuttgart) for inducing localised current drive (CD) at the magnetic island locations. Its main objective is to stabilise the Neoclassical Tearing Modes (NTM) which is achieved by steering the EC beams over a range of plasma areas (typically $\rho_p$ of 0.64 - 0.9) with a CD efficiency sufficient to stabilise 3/2 and 2/1 NTMs for the reference scenario 2, but also for the hybrid scenario (#3) and for the low-q operation (scenario #5) [1]. It is further desirable that the Upper Launchers can be used to access the q=1 region of plasmas with positive shear (function potentially shared with the equatorial launcher) to provide control of the sawtooth period and amplitude [2]. The current reference design achieves this functionality with 4 “Extended Performance front steering Launchers” or EPLs which cover $\rho_p$ of 0.4 - 0.9 [3].

2. Overview of the structural system
The structural system of each launcher integrates the mm-wave beam lines and their components. It consists of two separate units, namely the blanket shield module (BSM) forming the plasma-facing component and the launcher main structure, which includes the internal shield (cf. FIG. 1) [4]. The main structure is bolted at the launcher back-end as a cantilever to the port extension of the vacuum vessel. The BSM and the main structure are formed as welded assemblies.

The capability of the structural design to provide communality with diagnostics launchers as well as fabrication and cost considerations have led to the currently pursued “slim wall” design (cf. FIG. 2).
FIG. 1. Major parts of the structural system for the ITER ECH upper port plug and their connections

FIG. 2. Main components of the structural and mm-wave components of the current EPL design

The “slim wall” structural design is characterised by a single wall central section of the main frame (55 mm wall thickness), whereas the front section has double walls formed by plates of 30 mm each. The double wall socket area at the launcher back-end is formed by plates of 40 mm each to account for the particular mechanical strength needs near the launcher fixation to the port. In the double wall sections, meandering paths are formed for the input line of the main launcher cooling system fed by the blanket water primary heat transfer system (“blanket water”). Apart from very efficient and homogeneous heat removal which is particularly advantageous for removing the nuclear heat load generated at the front sections, the double wall sections serve together with the actively cooled internals as heater elements during bake-out when blanket water at 240°C and 4.4 MPa is fed into the main launcher cooling system.
The port plug accommodates the following groups of launcher internals:
- Mm-wave system (waveguides, mirrors, mitre-bends)
- Tubing for coolant supply and for the pneumatic system of the steerable mirrors
- Shielding elements inside the BSM and in the main frame

The main frame is connected to the BSM by a bolted joint, which allows axial access to the plug internals for maintenance and disassembly. A removable cover integrated into the top part of the single wall section allows vertical access to part of the internal shield.

3. The design of the shielding elements

Two individual shield blocks in the BSM have been adapted to mm-wave system (BSM) on the top and mid level segment. Their cooling lines are integrated into the main launcher cooling system by pipes feeding in the water from the BSM housing into the top-level shield block. After the circulation in the mid-level shield block, piping is provided for transfer into the internal shield segments which form the neutron shields in the main frame (cf. Fig. 3). The top-level shield block provides fixation and cooling of the focusing mirror, while the two steering mirrors are both equipped with a separate line of blanket water to allow independent operation of these key components in the mm-wave system.

![FIG. 3. The location of the shield blocks and the piping of the cooling connections in the BSM](image)

Given the actual geometry of the mm-wave beam configuration, the “encased shield block” concept is given preference over the potential alternatives, such as the “solid shield block” approach [4]. Particularly suited for large and regularly shaped volumes, the concept is based on filling a welded stainless steel (SS) casing with stacked SS plates and water interspaces which allows an equal distribution of water flow through the shield block (cf. Fig. 4). Furthermore, by adequate adaptation of the plate and interspace dimensions, the optimum SS to water concentration (80/20 vol. %) for the neutron shielding in the high flux area can be readily achieved.

The internal shield provides the major radiation protection of the launcher internals up to the launcher back-end and of surrounding structures, like part of the vacuum vessel and superconducting coils. Out of three possible design options (block, tank and modular design) [3], a combination of a modular design formed by a small number of individual plates in the front part and a block design formed by a metal block with machined cooling channels and
with potentially fully integrated waveguides is favoured by the kinked path of the mm-wave beams in the central section of the EPL (cf. Fig. 2).

![Diagram of Cask, Stacks of steel plate, and Assembly](image)

**FIG. 4** Design of the shield blocks in the BSM based on the “encased shield block” concept

### 4. Thermal analysis of the baking conditions

Since in the current slim wall design of the EPL, there are long paths in stainless steel for the heat to flow in the central single wall section, it is obvious that radiation heat transfer among components and to the environment will play a major role in the baking process.

![Diagram of temperature analysis](image)

**FIG. 5:** Design base for the temperature analysis for the baking process of the port plug in the surrounding vacuum vessel and port extension (top) and the profile calculated for the temperature distribution attained with a baking period of 100h (bottom).
Therefore the temperature analysis of the port plug system was performed by 2D finite element modelling using the ANSYS simulation tools including the heat loss due to radiation. The model, as given in FIG. 5, simulates the vertical mid plane of the launcher, of the vacuum vessel port and of the port extension. The equilibrium of the temperature distribution could found during the prescribed baking period of 100 h with blanket water at 240°C following a temperature ramp-up of 50h. At temperature equilibrium, all parts of the port plug attained temperatures above 200°C which is expected to give a sufficient margin to the minimum baking temperature of SS surfaces of 180°C.

5. Summary and outlook

A detailed consistent design has been developed for the ECH upper port plug structure which is composed of a detachable blanket shield module with dedicated internal components and of the main structure setting the frame for the mm-wave beams. The current detailed design of the shield blocks and of the internal shield provides the basis for the forthcoming revision and further detailing of the cooling routing and maintenance access.

The slim wall concept for the main frame takes benefit of an attractive option for relaxed baking scenarios and thus opens new paths towards enhancing the communality with diagnostic port plugs and the flexibility in the selecting competitive manufacturing routes. The latter advantage is due to reducing the size of double wall sections to less than 1 m, thus favouring the application of hot isostatic pressing and vacuum brazing technologies.

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References