

17 Electron Cyclotron Heating and Current Drive

17.1 Function, Basic Configuration and System Boundaries

The EC H&CD system consists of the following main elements:

- Launchers,
- Transmission lines,
- RF power sources,
- Power supplies,
- Controls, monitors and interlocks,
- Auxiliaries.

The EC H&CD system boundaries are as follows:

- bolted/welded connection of the launcher to the vessel port flange;
- bolted/welded connection of bellows, attached to a waveguide, to the cryostat port flange;
- coolant connection to the blanket and vessel cooling systems at a pipe flange in the cell before the bioshield;
- connection to the EC vacuum pumping system at a port of the RF conditioning unit and at ports in the vacuum pumped section of waveguide;
- attachments of transmission lines to the buildings between the cryostat port cover plate and the RF power source area of the building;
- positioning of the power supplies in a dedicated area within the building complex, including heating, ventilation and air conditioning of that area;
- connection to the additional heating power supplies at a terminal of the DCHV supply;
- connection to the RF power supply cooling system at a connector on each gyrotron unit;
- connection of the local controllers for subsystem control to the site CODAC system.

17.2 Requirements

17.2.1 General

- (1) The ECH&CD system shall provide electron heating in 50–50 % DT plasmas.
- (2) The ECH&CD system shall be capable of driving a continuous central current at the plasma axis of at least 200 kA/m² and a total current of greater than 1 MA-within $r/a < 0.6$ with a line average density of $5 \times 10^{19} \text{ m}^{-3}$ or greater.
- (3) The ECH&CD system shall be designed with sufficient instrumentation and control, also for system protection.
- (4) The system performance must be achievable over the performance range:
 - 70-100% of full toroidal field,
 - volume average plasma densities of $2 \text{ to } 20 \times 10^{19} \text{ m}^{-3}$.
 - temperature range $2.5 \leq T_e \text{ (keV)} \leq 12$.

- (5) All systems shall be designed with components that use existing technology or whose reliability can be demonstrated by R&D before being installed in ITER.
- (6) In-vessel components of the system shall be designed :
 - to be independently removable from the other basic structures;
 - to be protected by plasma-facing components similar in nature and resistance to plasma interaction to those of the primary FW.

17.2.2 Vacuum

- (1) The capability shall be provided, as necessary, to allow the in-situ leak testing of in-vessel components.
- (2) A combination of one window and one isolation valve shall be used for primary tritium confinement. The window shall be located at the VV closure plate. The isolation valve shall be located near the cryostat closure plate.
- (3) A combination of one rupture disc and a vault de-tritiation system (VDS) shall be used for secondary tritium confinement.

17.2.3 Mechanical

- (1) The EC H&CD system shall use the same structural material as the vacuum vessel for confinement structures linked to those of the cryostat. These structures must fulfil all the requirements of secondary and primary confinement boundaries.
- (2) Ex-vessel waveguides will be pressurizable to a minimum of 0.2 MPa.
- (3) The design shall be such as to allow movement of in-vessel components during transients and due to thermal expansion/contraction.
- (4) The EC launcher shall be rigidly connected (i.e. welded or bolted) to the vacuum vessel, according to the selected design option.
- (5) The penetrations for the waveguides through the vessel and the cryostat shall fulfil all requirements of a vacuum and confinement boundary.
- (6) Supports and windows will allow differential movements during thermal and mechanical transients. Flexible pressure boundaries shall be sealed with bellows.

17.2.4 Thermohydraulic

In-vessel Components

- (1) The structural integrity and function of these components shall not be destroyed following a transient contact with plasma for less than a few seconds.
- (2) Some components of the EC launcher will also experience a surface heat load due to RF ohmic dissipation and afterheat.
- (3) Baking of the EC H&CD in-vessel components inside the primary vacuum can also be provided by the controlled application of continuous or pulsed RF power at reduced coolant flow.
- (4) From a thermal viewpoint the EC in-vessel components shall appear equivalent to the surrounding blanket and vessel.
- (5) The torus window of a launcher shall be cooled by vacuum vessel cooling water.
- (6) The EC H&CD components must be compatible with water coolant chemistry. Specific requirements to limit corrosion, electrochemical, and other effects to acceptable levels over the life of the system.
- (7) Self-sustaining chemical reactions (such as steam reactions with plasma facing components) shall be precluded by designing for sufficient heat transfer to colder parts of the machine.
- (8) All in-vessel components shall be designed to be drained of water in-situ.

Ex-Vessel Components

- (1) Water from the component cooling water system (CCWS) will be used to cool the main transmission line beyond the torus window.
- (2) Gyrotrons and associated components including test loads are cooled by deionised water.

17.2.5 Electrical

- (1) The EC launcher is mechanically and electrically connected (earthed) to the vacuum vessel port closure plate.
- (2) Electrical isolation will require a DC break between tokamak and ex-vessel transmission lines, and between the ex-vessel transmission line and a gyrotron. Voltage standoff for these breaks is 1 kV.

- (3) Allocation of electro-insulating inserts and gaps in or between structural components shall restrict values of local and global eddy currents below specified levels. Particularly, design of all components should avoid use of doubled or multiple grounding points, that can create large loops for eddy currents.
- (4) Routing and design of grounding busbars, conduits, resistors and jumpers shall be chosen in order to limit voltages below specified levels in case of earth fault for any considered events sequence.
- (5) The grounding scheme for structural components should minimize the possibility of propagation of electrical breakdown, including modes with diffuse discharges and arcs in vacuum volumes for a wide range of gas pressure, in presence of water or steam.
- (6) Continuously operated RF power radiation monitors shall be installed in the generator hall and at DC breaks. Their outputs shall be part of the EC interlock system.
- (7) All power transmission equipment shall be of the corrugated waveguide type.
- (8) No signal transmission of baseband signals will take place. The RF signals detected at the monitoring points shall be down-converted at the detection point.
- (9) All signal exchanges between different EC subsystems and between EC and other systems shall be via fibre optic links.
- (10) Thin (50 μm), low resistance (Cu) coatings may be required to reduce RF losses in some in-vessel components.

17.2.6 Remote Handling

- (1) In hot cell renewal, low Z (beryllium) coatings should be foreseen for the plasma-facing components and an in-vessel mirror replacement should be foreseen depending on surface damage of the mirror.
- (2) The individual maintenance of a torus window should be possible without disassembly of the EC launcher.
- (3) The launcher shall be removable from a port. Any interruption of the ITER operation due to this removal should be minimized by appropriate design to make the launcher as reliable as possible.
- (4) Gripping points capable of supporting the full weight over the full range of motion required at installation or removal must be provided on all remotely maintained components.
- (5) The structural supports, coolant lines joints, instrumentation leads, and all other interfaces must be compatible with the capability of the remotely operated tools.

- (6) The design must ensure sufficient space for the insertion and removal of all required tools.
- (7) All liquid and gas pressure bearing joints must be capable of being leak detected by remote means.
- (8) Mechanical guides shall be provided to aid the transporter for final positioning and alignment and to protect adjacent components from damage due to collisions.
- (9) Periodic visual inspection of the in-vessel components shall be required to assess possible damage.
- (10) Facilities for dedicated leak testing of transmission lines shall be provided.

17.2.7 Manufacturing

- (1) Manufacturing tolerances shall be consistent with achieving the overall installation tolerances, taking into account inaccuracies resulting from installation and tolerances of mating components.
- (2) The in-vessel components shall be fabricated as a set of modular components and sub-assemblies capable of being assembled by a contractor at the construction site. The system shall be assembled using a plan that is compatible with the project's general assembly plan. The assembly plan will be developed considering facility restrictions on size and handled weight.
- (3) The system will provide special tools and fixtures for use in on-site assembly and installation.
- (4) All inner and outer surfaces of the vessel port plug are to be cleaned with a solvent (acetone, alcohol, or equivalent) and then air-dried.

17.2.8 Assembly

- (1) Sufficient gaps must exist between the EC launcher and the surrounding blanket modules to account for fabrication misalignments, off-normal events, and thermal expansion due to normal operation and baking.
- (2) Sufficient gaps must exist between waveguides and the cryostat closure plate and the bioshield to account for fabrication misalignments, off-normal events, and thermal expansion due to normal operation and baking.