

18 Lower Hybrid Heating and Current Drive System

18.1 Functions, Basic Configuration and System Boundaries

The Lower Hybrid Heating and Current Drive (LH H&CD) system consists of:

- launching structure(s) composed of:
 - array(s) of passive/active waveguides (passive/active multijunction arrays –PAM)
 - splitting networks and mode converters
 - neutron shield and support structure;
- main transmission lines;
- RF power sources;
- electrical power supplies sets;
- decoupling units;
- monitoring and controls;
- auxiliaries and services.

The LH H&CD system boundaries are as follows:

- bolted attachment flange of the RF plug to the vacuum vessel port flange not including the primary vacuum seal;
- bolted connection of the LH main transmission lines to the cryostat cover plate, including the seal for the secondary vacuum;
- coolant connection to the blanket and vessel cooling systems at a flange at the cryostat cover plate;
- attachments for getter pumps and vacuum monitoring equipment;
- attachments of transmission lines to the buildings between the cryostat port cover plate and the power supply area;
- connection to the additional heating power supplies at the high voltage terminal of the RF power source;
- location of the RF power sources supplies in a dedicated heated, ventilated and air conditioned area within the building complex;
- connection to the RF power supply cooling system in the RF power sources hall;
- connection of the local plant controller to the site CODAC control system

18.2 Requirements

18.2.1 General

The LHH&CD system shall provide electron heating and off-axis current drive, peaking at the flux surface y where $n_e(y) \cdot T_e(y) = 10\text{-}15 \text{ keV} \cdot 10^{20} \text{ m}^{-3}$, with a typical current drive efficiency

$2 < \eta_{CD} < 3 \times 10^{20} \text{ m}^{-2} \text{ MA/MW}$, in any plasma scenario and/or discharge phase. In particular, the system shall be able to drive a continuous off-axis current of at least 3 MA within $r/a < 0.5\text{-}0.7$ with a line average density of $5 \times 10^{20} \text{ m}^{-3}$ or greater.

The system shall be designed to operate at the frequency of $5.0 \text{ GHz} \pm 5 \text{ MHz}$ (3dB-break point)

and shall be equipped with instrumentation for the automatic control of RF power, frequency, and phase. Automatic protection against voltage breakdown in load, transmission and power source shall be included in the design.

All LH system components shall use technology currently available or whose reliability R&D can demonstrate before being installed in ITER.

An efficient coupling between the launcher and the plasma requires a plasma density $4 \cdot 10^{17} < n_e < 10^{17} \text{ m}^{-3}$ between launcher and plasma separatrix. Active control of the plasma edge density at the required value shall be part of the LH system, if this condition is not naturally achieved.

18.2.2 Vacuum

Ceramic feed-throughs (vacuum windows), located at the VV closure plate in each waveguide are to be used for primary vacuum containment at the vacuum vessel. Similar feed-throughs shall be used to contain the secondary vacuum at the cryostat closure plate.

A rupture disk, exhausting to a vault de-tritiation system (VDS) shall protect the vacuum window in the secondary confinement boundary against overpressure.

18.2.3 Mechanical

Ex-vessel transmission lines and vacuum windows shall withstand a continuous pressure up to 0.2 MPa.

Thin, low resistance (50 μm) metallic coatings (Cu, Be, Ni) may be required to reduce RF losses in some in-vessel components.

18.2.4 Thermohydraulic

In-vessel Components

In addition to plasma radiation and volumetric nuclear heat loads, Some components of the LH launcher will experience a surface heat load due to RF ohmic losses up to 4% of the transmitted RF power.

The plasma-facing component shall not be designed to withstand thermal conduction loads from the plasma, (e.g. during the start-up phase), from which they shall be protected by the adjacent shielding blanket modules or by suitable protections integrated in the blanket.

In addition to the standard baking procedures, baking of the LH in-vessel components can be provided by the controlled application of continuous or pulsed RF power at reduced coolant flow.

The LH 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.

All in-vessel components shall be designed to be drained of water in-situ.

Ex-Vessel Components

RF test and matched loads present in the systems may use, for power dissipation, liquid resistors, circulated in a closed loop and cooled by heat exchange by water from the component cooling water supply (CCWS) system

18.2.5 Electrical

The reliability of the LH H&CD system operation depends on the maximum RF operating voltage. The maximum electric fields anywhere reached in the launching and/or transmission system, should not be in excess of 5.0 kV/cm. Effort should be made in the design, to further lower the above values, in particular the on-plasma voltage.

Allocation of electrically isolated gaps and inserts in or between structural in-vessel components shall restrict values of local and global disruption induced currents below safe levels. The design should avoid the use of double or multiple grounding points, as they can create large loops for RF or low frequency induced currents

Design and routing of grounding connections (busbars, cooling conduits, resistors jumpers, etc.) shall be chosen so as to limit RF voltages below the specified values. The grounding scheme should minimise 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.

All RF and DC power generation equipment shall be contained in sealed enclosures against electromagnetic interference (EMI). All power transmitter components (including DC supplies) shall be further enclosed in a second overall EMI sealed enclosure.

Continuously operated radiation monitors shall be part of the interlock system of the IC system, and shall prevent high power operation at any level of EMI above the specified threshold.

All power transmission lines shall be shielded and preferably of the coaxial type. No transmission of base-band low-level signals shall take place in the system. The RF signals detected at the monitoring points shall be down-converted, before transmission, to an intermediate frequency (IF) much lower than the operating frequency, to improve noise immunity. All signal exchanges between different IC subsystems and between IC and other systems shall be via fibre optic links

18.2.6 Remote Handling

The LH launcher shall be removable from the equatorial port by remote handling. Any interruption of the ITER operation, due to this removal should be minimised by appropriate design. It should be possible to maintain vacuum windows in situ, without disassembly of the launcher.

The structural supports, coolant lines joints, instrumentation leads, and all other interfaces shall be compatible with the capability of the remotely operated tools. 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. The design must ensure sufficient space for the insertion and removal of all required tools.

All liquid and gas pressure bearing joints must be capable of being leak detected by remote means.

Mechanical guides shall be provided to aid the transporter for final positioning and alignment and to protect adjacent components from damage due to collisions.

Renewal of low Z (beryllium) coatings of the plasma-facing components may be performed in the hot-cell.

18.2.7 Manufacturing

Manufacturing tolerances shall be consistent with achieving the overall installation tolerances, taking into account inaccuracies resulting from installation and tolerances of mating components.

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.

Any special tools and fixtures for use in on-site assembly and installation shall be provided as part of the LH system.

All inner and outer surfaces of the vessel components are to be cleaned with a solvent (acetone, alcohol, or equivalent) and then air-dried.

18.2.8 Instrumentation & Control

(The control of the plasma position (gap) in front of the LH launcher shall be automatically performed by using the radiative loss (coupling) as feedback signal

All RF components exposed to high RF voltage shall be continuously monitored by fast arc detection monitors. The pressure in the main transmission line shall be continuously monitored and controlled above the threshold value. No high power RF operation shall be possible without these two monitors operative.