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Overview of the ITER Electron Cyclotron H&CD System

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A 24 MW EC H&CD system is under development to be installed on the ITER Tokamak. A combination of two types of launchers, one located in the equatorial port and four in the upper ports will used for the various physics applications. Gyrotrons are designed to generate a minimum power of ≥0.96MW at the frequency of 170 GHz, at the MOU (Matching Optic Unit) output with ≥95% coupling to the HE_{11} mode and an electrical efficiency of ≥50%. The transmission line is designed to transmit the EC power from the gyrotrons up to the launcher with an overall transmission efficiency of ≥90% and 97% degradation of HE_{11} content from the output of the MOU.

1. Design of the EC system

A 24 MW Electron Cyclotron Heating and Current Drive (EC H&CD) system is under development to be installed on the ITER Tokamak, for plasma startup, central H&CD and control of MHD activity. A combination of two types of launchers, one located in the equatorial port and four in the upper ports will be used for the various physics applications required from the EC H&CD system, partitioned according to the launcher's deposition location and driven current profiles. All subsystems will be in-kind procurements, delivered by 5 parties: Europe is responsible for delivering 8 MW for the H&CD (Heating and Current Drive) gyrotrons, part of HVPS and the four upper launchers (UL); India is responsible for procuring 2 MW for the H&CD gyrotrons and remaining HVPS; Japan is responsible for delivering 8 MW for the H&CD gyrotrons and the equatorial launcher (EL); the Russian Federation is responsible for procuring 8 MW for the H&CD gyrotrons; US are responsible for delivering all the Transmission Lines (TL), from the gyrotrons up to the launchers.

The EC system is designed to fulfill the following functionalities:

- Provide auxiliary heating to assist in accessing H mode and achieve Q=10.
- Provide central heating and current drive over the range of 0 to 0.45.
- Control MHD instabilities by localized current drive over the range of 0.3 to 0.9.
- Assist initial breakdown and heat during current ramp-up.
- Provide one third of the total power for counter-ECCD over the range of 0 to 0.45.
- Provide on/off power modulated from CW to 1 kHz and 100% to >50% power modulated from 1 to 5 kHz.

The EC system is distributed over 3 buildings, from the HVPS to the launchers. Most of the equipment is installed in a dedicated building together with the IC system, except part of the TL running along the walls in the Assembly hall and the launchers. HVPS are a PSM-based system, commercially available and consist of a main power supply (MHVPS, 55kV/90A, up to 1kHz modulation capability), body power supply (BPS, 35kV/50mA, up to 5kHz modulation capability) and, in the case of the triode gyrotrons procured by Japan, anode power supply APS (45kV/50mA, up to 5kHz modulation capability). Each MHVPS is connected to two 1MW (or one 2MW) gyrotrons, whereas all gyrotrons have individual BPS and APS (when required).

The gyrotrons are designed to generate a minimum power of ≥0.96MW at the frequency of 170 GHz, at the MOU (Matching Optic Unit) output with ≥95% coupling to the HE_{11} mode and an electrical efficiency of ≥50%. The gyrotron procurement includes a liquid helium free cryomagnet, MOU, cooling manifold, local control system, support structure, auxiliary power supplies and ancillary systems. Various prototypes are tested by each party, with very good results from RF and JA: 1.02MW/570s (with an efficiency of ~55%) have been achieved in Russia, and 1MW/800s/55% and 1h operation at 0.8MW with a very stable oscillation and an efficiency of 57% have been demonstrated in Japan. Reliability tests to simulate ITER environment have shown very promising results, close to 90%, by JA and equivalent performance by RF in preliminary tests. In addition, JA has demonstrated full power modulation operation at the frequency of 5kHz during a 60s-pulse by switching the anode voltage.

The transmission line is designed to transmit the EC power from the gyrotrons up to the launcher diamond windows in the equatorial and upper port cells with an overall transmission efficiency of ≥90% and 97% degradation of HE_{11} content from the output of the MOU. At present, TL components are currently commercially available for 1 MW and extension to 2 MW requires additional R&D for critical components.

One EL will be installed in port 14, with 24 entries, organized in 3 rows of 8 beams. Its design is proposed to be changed from 3 steering mirrors that sweeps the beams in a pseudo toroidal plane to sweeping in a pseudo poloidal plane with a fixed toroidal injection at ~27° for at least 2/3 of the beams (the remaining 1/3 would be injected for counter ECCD). The change provides increased deposition of the EC power across the plasma cross section, increased driven current and potential reduction in neutron streaming through the launcher. Four Upper Launchers (UL) will be installed in ports 12, 13, 15, 16. Each UL is made of 8 entries, organized in 2 rows of 4 beams. The 4-beam set propagate through the launcher via 3 fixed and 1 steering mirrors. The two steering mirrors (lower and upper) give access to different regions in the plasma for a total coverage of $0.3<\rho_T\leq 0.86$. R&D is going on for both antennas.

2. EC physics functionalities

ITER will need Electron Cyclotron assisted plasma breakdown to conserve volt-second from the central transformer. Thus the EC system will be installed for initiating the first plasma, planned in 2020. Note that during the first years of operation, ITER will be operating at reduce fields (typically around half field), the resonance associated with 170GHz is found in the null region for a majority of the operating magnetic field space between half and full field operation. Physics applications are split between the EL and the UL. The UL are used mainly for MHD control (Sawtooth and NTM stabilization), while the EL is the main launcher for the H&CD applications, offering central access. The proposed EL modification (poloidal scanning mirrors with a fixed toroidal injection) would provide access out to $\rho_T\leq 0.6$ and double the driven EC current in the range of $0.4\leq\rho_T\leq 0.6$.

3. Schedule

The first EC procurement arrangement (PA) was signed with the US for the Transmission line. This year, two additional PAs are planned to be signed, one with the Russian Federation for one third of the sources and the second with Europe, for part of the High Voltage Power Supplies (HVPS). Design of the RF building housing both IC and EC systems is close to its finalization, to be made available before November.

Only one third of the original 20 MW of EC system is required to be operational for the first plasma, whole EC system will be available for second phase. The design, manufacturing, installation and commissioning activities are organized according to these milestones prior to the planned plasma initiation date. The installation process will begin in early 2016 when the RF, Assembly and Tokamak buildings are available for EC equipment installation.

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