SI-2

［ECシステムの設計開発の進展］

Design Progress on ITER Electron Cyclotron Heating & Current Drive System

大森俊道, T. Omori[1], F. Albajar[2], S. Alberti[3], K. Avramidis[4], U. Baruah[5], T. Bigelow[6], T. Bonicelli[2], A. Bruschi[7], R. Chavan[3], F. Cismondi[2], C. Darbos[1], G. Denisov[8], A. Dumur[9], D. Farina[7], F. Gandini[1], G. Gantenbein[10], T. Gassmann[1], T.P. Goodman[3], G. Hanson[6], M.A. Henderson[1], J.P. Hogge[3], J. Jelonnek[10], K. Kajiwara[11], W. Kasparek[12], N. Kobayashi[11], M. Kushwah[1], G.P. Latsas[13], A. Moro[7], C. Nazare[14], Y. Oda[11], A. Oustinov[8], I. Pagonakis[10], B. Piosczyk[10], L. Popov[8], D. Purohit[1], S.L. Rao[5], D. Rasmussen[6], D.M.S. Ronden[15], G. Saibene[2], K. Sakamoto[11], T. Scherer[10], M.A. Shapiro[16], N. P. Singh[5], C. Sozzi[7], P. Spaeh[10], D. Straus[10], O. Sauter[3], K. Takahashi[11], R.J. Temkin[16], H. Zohm[17]

[1] イーター機構, ITER Organization, Route de Vinon sur Verdon, St. Paul-lez-Durance, 13115 France
[2] Fusion for Energy, C/ Josep Pla 2, Torres Diagonal Litoral-B3,E-08019 Barcelona – Spain
[3] CRPP, Association EURATOM-Confédération Suisse, EPFL Ecublens, CH-1015 Lausanne, Suisse
[4] SECE, National Technical University of Athens, Greece
[5] Institute for Plasma Research, Near Indira Bridge, Bhat, Gandhinagar, 382428, India
[6] US ITER Project Office, ORNL, 055 Commerce Park, PO Box 2008, Oak Ridge, TN 37831, USA
[7] Istituto di Fisica del Plasma, Association EURATOM-ENEA-CNR, Milano, Italy
[8] Institute of Applied Physics Russian Academy of Sciences, 46 Ulyanov Street, Nizhny Novgorod, 603950 Russia
[9] C-con, ZAC Rourabeau, St. Paul-lez-Durance, 13115 France
[10] KIT, Association EURATOM-KIT, IMF, Postfach3640 D-76021 Karlsruhe, Germany
[11] Japan Atomic Energy Agency (JAEA) 801-1 Mukoyama, Naka-shi, Ibaraki 311-0193 Japan
[12] Institut fur Plasmaforschung, Universitat Stuttgart, Pfaffenwaldring 31, D-70569 Stuttgart, Germany
[13] National and Kapodistrian University of Athens, Greece
[14] Assystem Facilities, 23 Place de Wicklow CS 30713, 78067 Saint Quentin en Yvelines Cedex
[15] Association EURATOM-FOM, 3430 BE Nieuwegein, The Netherlands
[16] MIT Plasma Science and Fusion Center, Cambridge, MA 02139, USA
[17] IPP-Garching, Association EURATOM-IPP,D-85748 Garching, Germany

Overview

An Electron Cyclotron (EC) system is one of four auxiliary plasma heating systems to be deployed in ITER [1]. The EC system consists of 170 GHz gyrotrons (RFPS; RF power source) with associated high voltage power supplies (HVPS), a set of evacuated transmission lines (TL) and launchers, is designed to inject ≥ 20MW of microwave power into the plasma for plasma start-up, central H&CD and control of MHD activity on the ITER Tokamak.

The ITER EC system is expected to realize the challenges as an advanced microwave device for the future plasma heating and current drive applications. CW operation with 20MW injected power represents a large step forward in the use of the EC system as compared to the present state of the art. It is anticipated difficulties in the development and installation with complicated procurement strategy under the international cooperation project. It is noted that ITER became the first fusion device qualified as basic nuclear installations as of 9 November 2012. The EC system especially for launchers shall comply with specific requirements associated with nuclear safety.

EC system description

The EC system is installed in three buildings (see figure 1). Building 15 houses the 12 HVPSs, 24 RFPSs and part of the TLs. The TLs pass through the Building 13 to Building 11. The TLs offer a low loss transmission of the microwave power from RFPS to the launchers (~160m in length). Two types of launchers are installed in Building 11, the first type located in an equatorial port (EL; Equatorial Launcher) and the second type located in four upper ports (UL; Upper Launcher). There are several Physics applications required of the EC system, which partitions these applications between the EL and the ULs. For the first plasma on ITER, one third of the EC power is required while full power of 20 MW will be available by the second phase.

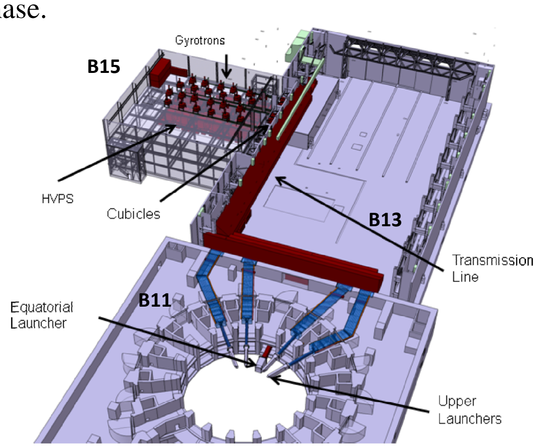

Fig. 1 Layout of the EC system with the power supplies and 24 gyrotrons in B15 (the RF Building, upper left) and the transmission lines passing through B13 (the assembly hall) to B11 (the tokamak building) leading to the four upper and one equatorial launchers.

These subsystems are integrated together by introducing a modular structure[2] to provide a maximum operating flexibility and minimum impact arising from component failure, e.g., a single HVPS is feeding for two 1MW gyrotrons such that the delivered power can be isolated in 2 MW increments when subsystem fails.

The HVPS system consists of 12 main, 24 body and 8 anode (for triode gyrotrons) power supplies. They will be procured by Europe and India domestic agencies (DAs). The HVPSs are designed to use the pulse step modulation technology which enables fine voltage control with high frequency modulation for gyrotron operation.

The RFPS is comprised of 24 gyrotrons which will be supplied by four DAs of Europe, India, Japan and Russian Federation. The output beam of which TEM_{00} mode at the gyrotron's diamond window is to be converted to HE_{11} mode by the Matching Optics Unit for highly-efficient coupling with TL subsystem.

The TL subsystem is comprised of 24 lines of corrugated waveguides with associated brunched sections and components to guide RF power to either the EL or the ULs. The TL also controls the polarization for optimum plasma coupling, monitors the RF power during operation and switches the power to load for gyrotron conditioning. To avoid the unnecessary losses, the TL routing is designed to minimise the number of the mitre bends which are between 7 to 9. The TL subsystem is going to be provided by the US DA.

Two launchers are planned to achieve the required functionality of central H&CD and the off-axis CD for stabilizing MHD activity. These functions will be fulfilled by the right combinational use of the EL and the ULs. The launchers are procured with the ex-vessel millimetre wave subsystem which is comprised of the diamond windows, the isolation valves and roughly 15 m length of the ex-vessel waveguides. These components together with the closure flanges of the launchers form the first confinement barrier. In addition, waveguide compensates for the torus displacements (≤±25mm) due to temperature variations, plasma disruptions, thermal quenches and loss of coolant without any damage on the first confinement function.

The single EL is to be deployed at the equatorial port #14 and will be procured by Japan DA. A total number of 4 ULs are going to be deployed in the upper ports #12, 13, 15 and 16 with ex-vessel millimetre wave subsystem for both EL and ULs will be by Europe DA.

Future advancement

The EC system design is progressing towards the final stage according to the 2020 first plasma date with aiming at further enhancement of the EC system capabilities. The ITER EC section is proactive in promoting collaborations and joint efforts among the international EC community, through contracts and task orders, with the aim to address the challenges and new technology development needed to successfully achieve the ambitious ITER requirements.

R&D is on-going to confirm reliable performances: the gyrotron prototypes by both Japan and Russian DAs have operated for 1MW and ≥800sec; the launcher final designs are advancing using a series of on-going task agreements by Europe DA and Japan DA; the whole EC system is controlled by the EC control system, which is a new procurement arrangement to be established with Europe DA and Japan DA; and the functional capabilities of the EC system are being validated by EC beam physics analysis which verifies the heating and current drive potential for each plasma operation scenario and to study power management from break down to end of ramp-down.

Future modifications under consideration include: increase HVPS specifications to accommodate possible future EC power upgrade up to 1.4 MW per gyrotron; removal of Be from the first wall for the EL and the ULs and introduce a 10 cm recession from the neighbouring wall mounted blankets; and modification in the EL beam scan direction from toroidal to poloidal plane in order to double the driven current capability especially at mid radius (see figure 2).

These challenges can offer a simplified technical design and increase the functional capabilities of the EC system for plasma heating and current drive applications.

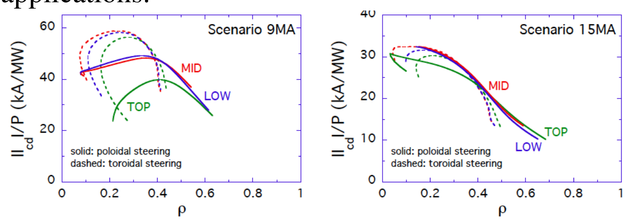

Fig. 2 The Project Change Request No. 505 has accepted into the baseline for implementation, is proposing EL to have poloidal beam scan, enables doubling EC CD capability in region of 0.45 <ρ<0.6.

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

[1] T. Omori, et al., Fusion Eng. Des. (2011), doi:10.1016/j.fusengdes. 2011.02.040

[2] M. Henderson and G. Saibene, Nucl. Fusion 48 (2008) 054017