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EU developments of the ITER ECRH system

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Abstract

The EU will be providing the largest contribution to the ITER electron cyclotron (EC) heating and current drive (H&CD) system (20 MW, CW at 170 GHz). The contribution includes one third of the H&CD gyrotrons, their associated power supplies and four upper port launcher antennas. In all areas of participation, the EU EC partnership (coordinated by the European Fusion Development Agreement) aims toward advancing the technology, while staying within a specified cost envelope. This is portrayed in the co-axial gyrotron development that offers the potential to double the output power per source (2.0 MW), increasing the delivered power for a fixed number of auxiliary systems. The EU partnerships also attempt to increase performance for the entire EC system, in particular the launching antennas. The proposed front steering launcher design offers greater control of MHD activity than the previous remote steering design and opens up the possibility of an enhanced performance UL. The EC physics

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requirements are repartitioned between the upper and equatorial launchers for a synergetic balance, which increases the EC physics capabilities while relaxing some of the engineering requirements.

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1. Introduction

The electron cyclotron (EC) heating and current drive (H&CD) system of ITER [1] will deliver 20 MW CW to the plasma at 170 GHz for H&CD applications in addition to ∼2.5 MW 3 s at 120 GHz for plasma start-up [2]. The EC H&CD system is composed of high voltage power supplies (HVPS), up to 24 H&CD gyrotrons (1–2 MW tubes), 3 start-up gyrotrons (1 MW tubes), 24 transmission lines and two sets of launching antennas: equatorial (EL) and upper (UL) launchers, as shown in Fig. 1. Under the present ITER procurement packages [3] the EU is responsible for one third of the H&CD 170 GHz gyrotrons, all HVPS associated with the H&CD system, and the whole set of four upper launchers. The EU has one of the most significant contributions to the ITER EC H&CD system.

In all areas of participation, the EU EC partnerships (coordinated by the European Fusion Development Agreement—EFDA) aim toward advancing the technology of each of these subsystems, while staying within a cost envelope and optimising the performance and reliability. For example, procurement of fast, IGBT based, power supplies is under analysis [4,5], which could have equivalent costs to the present ITER design (thyristor HVPS and HV series switch), but with an increased flexibility in operation and variation in the EC power waveform. The EU is at the forefront in gyrotron research and is developing a 2 MW CW 170 GHz coaxial cavity gyrotron [6,7], offering an increase in output power while minimising the auxiliary systems needed per MW of generated RF power. A 2 MW, CW gyrotron test facility [4,8], is being built at CRPP that will be used to develop the 2 MW coaxial tube, in addition to testing various components required by the EC H&CD system.

EFDA has undertaken a parallel development of two launcher options: front (FS) [9] and remote (RS) [10] steering, with the aim of providing an optimum launcher for ITER, weighing EC physics aspects and operation reliability. These studies have led to the selection of a FS Upper Launcher as the reference design for ITER, while the EU is keeping the RS option as a back-up solution. The principle role of the UL is to stabilise neoclassical tearing modes (NTM) [11]. However, an enhanced performance UL launcher is under investigation by EFDA, seeking synergy between the EL and UL that would extend the physics potential of both launchers for an enhanced ITER EC physics performance [12], while at the same time relax some of the engineering requirements.

These activities are described in the following sections starting from the power supplies (see Section 2), then gyrotron development (see Sections 3 and 4), launcher (Section 5) and finally the physics analysis (Section 6). A summary and acknowledgements are provided at the end of the paper.

2. Power supplies

There will be two types of power supplies powering the ITER gyrotrons: main high voltage power supply (MHVPS) and a body power supply (BPS) as illustrated in Fig. 2a. The MHVPS is planned to be a Thyristor type PS [13] and provide the main voltage (∼60 kV) and current (∼500 A) to 12 depressed collector gyrotrons [14]. The BPS is used to de-accelerate the electrons prior to the impact with the collector for improved efficiency of up to 50%. A HV Semiconductor Series Switch (HVSSS) is used to provide the primary protection for the gyrotrons and disconnect them in pairs from the MHVPS.

Twelve solid state switching fast converters PS (SSSPS) [15] could be used in place of two thyristor PS eliminating the need for the HVSSS (see Fig. 2b) and offering greater flexibility in control of the RF power. The SSSPS have been in use for several years on the 4.5 MW ECH system [16,17], installed on TCV and are compatible [18] with ITER requirements with