Self-consistent modelling of STEP flat top scenario with realistic ECRH and ECCD

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1. Introduction

STEP is the UK's Spherical Tokamak reactor design program that aims to demonstrate the net electrical gain through the STEP Prototype Powerplant (SPP) [1]. SPP is being designed to use an exclusively microwave-based heating and current drive (HCD) system employing a combination of Electron Cyclotron (EC) and Electron Bernstein Waves [2]. Presently, a steady-state scenario is being developed for Electron Cyclotron Resonance Heating (ECRH) and Current Drive (ECCD) which uses prescribed EC power deposition and current drive profiles. The prescribed ECCD profile is based on an analytic formula capturing the temperature and density dependence [3]. The current drive profile is sensitive to the plasma parameters, i.e., density, temperature, impurities, but also subjected to limitations due to constraints on possible launcher positions (Fig. 1). The present work discusses fully self-consistent scenario modelling with realistic HCD. A series of iterative optimisation tasks was performed including (i) finding optimised launching parameters which will provide requested heating and CD profiles [4] and (ii) benchmarking the evolution of plasma parameters versus the requirements of the reference steady-state operating point.

2. Gray Ray Tracing

The GRAY [5] code was used for ECRH and ECCD calculations in this study. In the work reported here, the beam-tracing code designed to compute the quasi-optical propagation of Gaussian beams of EC waves in tokamak equilibria, together with the power absorption and driven current. In this reported work, GRAY has been used both independently (standalone version) and in conjunction with the JETTO plasma transport code, both being part of the JINTRAC suite of codes.

GRAY was initially used as the stand-alone code to perform single-ray parametric scans over the range of possible launching angles (poloidal and toroidal) and frequencies for all the prescribed launchers for an O and X mode launch [6]. These parametric scans (in EC frequency, power and launching angles) are based on snapshot of the equilibrium and the plasma profiles from the steady-state scenario for a prescribed heating and current drive profile. The scans over all the launchers provide comprehensive dataset to determine the optimum and best positions for the launchers across plasma radius. An optimum set of launching conditions was identified through GRAY parametric scans to achieve maximum current drive efficiency.

The GRAY code was subsequently re-run for the selected launchers, using a 6cm beam waist. To obtain the EC power in each launcher, the total power and current drive profiles from GRAY were linearly scaled to match the reference steady-state case. The optimized launching conditions (power, launching angles, and frequency) obtained from stand-alone GRAY scans are used as inputs for the plasma transport code JETTO as described in the next section.

3. JETTO/GRAY Self-Consistent Run with Realistic EC Launchers

The JINTRAC suite of codes is used to model self-consistent plasma scenario [7] in tokamak fusion devices. It incorporates various modules and subroutines for modelling plasma equilibrium, transport, heating, and current drive with the aim of providing a comprehensive understanding of plasma behaviour. As mentioned earlier, the reference scenario, referred to as SPP-45 here, which relies on EC heating and current drive, assumes a prescribed power density and current drive profile. This profile is determined using an analytic formula that takes into account the temperature and density dependence. The objective of this study is to continue the reference flat-top run by replacing the predetermined heating and current profiles with realistic profiles derived from an optimized set of EC launchers obtained as described in section 2. JETTO calls the subroutine GRAY at every user-defined time-interval or whenever there are changes in the plasma profiles or equilibrium. GRAY, integrated with JETTO and GRAY-standalone have been checked to give identical heating and current-drive profile. Fig. 1 displays the set of EC launchers utilized in the self-consistent JETTO/GRAY runs, including the beam trajectories and the corresponding launching conditions.

LP	R (m)	Z (m)	Mode	f (Ghz)	Pol. (deg)	Tor. (deg)	P (MW)
L1	5.75	-3.30	O	170	-42.5	-25	40
E1	4.25	5.30	O	210	65	-25	36
F1	4.75	4.70	O	185	60	-25	31.2
M2	4.25	-5.30	O	150	-50	-25	8.6
M3	4.25	-5.30	O	160	-47	-25	6.2
H1	5.75	3.30	O	165	45	-25	6
E2	4.25	5.30	O	135	57	-25	4.9
E3	4.25	5.30	O	215	65	-25	4.3
M4	4.25	-5.30	O	160	-45	-25	2.9
M5	4.25	-5.30	O	160	-47	-20	2.1
M6	4.25	-5.30	O	160	-40	-20	0.8
E4	4.25	5.30	O	145	60	-20	6
E5	4.25	5.30	O	140	55	-25	10
G1	5.25	4.00	O	160	55	-20	4

Table 1 EC Beam Launchers

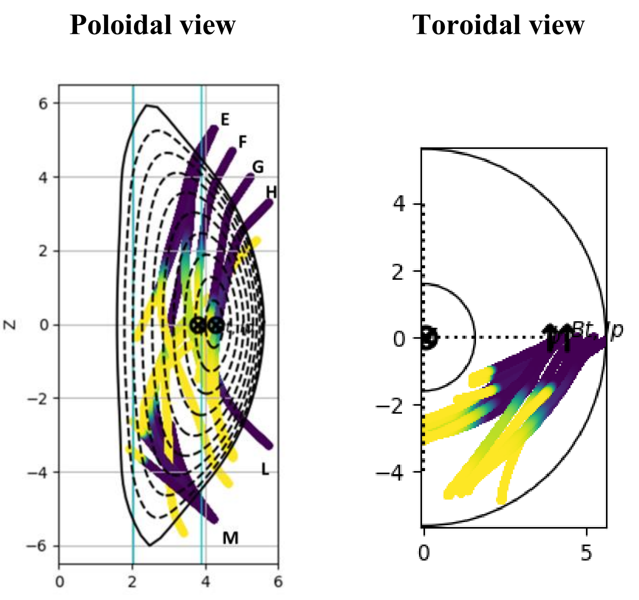

Figure 1 *Table 1(left) displays the set of EC beam launchers (Launch points (LP), R, Z) along with their corresponding launching parameters (frequency, launching mode and angles, power per launcher) used in the self-consistent run along with the poloidal and toroidal view of the beam trajectories inside the plasma (right)*